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Vol. 219 MAY, 1935 No. 5

STEAM TURBINES.*

(A Review.)

BY

FRANCIS HODGKINSON

Consulting Mechanical Engineer,
Westinghouse Electric and Manufacturing Company.

It seems that most attempts to obtain mechanical power from heat up to the time the reciprocating steam engine had reached a considerable degree of development, were made by means of turbine principles, but the useful and practical development of the steam turbine has taken place within less than the last 50 years. I think it is true, however, that nearly every modern turbine principle was discovered much earlier.

During this 50-year period, there have been innumerable inventions covering arrangements of parts, details of construction such as blade fastenings, stator and rotor structures, labyrinth and gland packings, regulating mechanisms, etc., but there have been only two or three inventions touching turbine principles. A factor of no small importance to the progress of the steam turbine has been the development of allied machinery, such as electric generators to operate at speeds appropriate to those of the steam turbine; condensers to sustain low exhaust pressures to which

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

the turbine, but not the reciprocating engine, could be made capable of expanding usefully; steam-generating apparatus capable of supplying higher and higher pressures and temperatures, of which, especially temperature, the reciprocator could not easily be made to avail itself.

Following the development of the reciprocating steam engine, which might be said to have occupied, roughly, the period between 1770 and 1820, the possibilities of turbine principles seem to have been temporarily unrecognized. This is not to be wondered at because engineers of that day surely saw far more promise in a machine in which steam expanded behind a comparatively leakless piston than in one which utilized either the reactive force of a jet of steam or the force resulting from it being squirted against some form of bucket.

The mechanical and metallurgical arts of that day hardly would have rendered possible the construction of a steam turbine having the efficiency and reliability of even the contemporaneous reciprocating engine much less that of the modern steam turbine so that the steam turbine is indebted to the reciprocating steam engine for having brought about the development of machine shop and foundry practices which paved the way for itself. The steam turbine, in its turn, has brought about yet further machine shop and metallurgical development. Electric-arc welding, for example, has profoundly affected machine-shop practice and has, to no small extent, displaced the foundry and small forge.

What might be called a "renaissance" of the steam turbine came with the work of Sir Charles Parsons, which commenced in 1884.

By common consent, Sir Charles is regarded as the progenitor of the modern steam turbine. It is not my purpose, however, to indulge in a eulogy of him, because I would regard such an act on my part as savoring of impertinence. It has, however, been my honor and my privilege to have enjoyed his friendship and to have been associated with his work in connection with the earliest steam turbines that he constructed.

I believe, but I have never heard it said, that Sir Charles' attention was originally directed to the possibilities of the steam turbine because of some experiments with war rockets

which he undertook during his apprenticeship with Sir Wm. Armstrong, which caused him to realize the forces that are the result of gases expanding through nozzles.

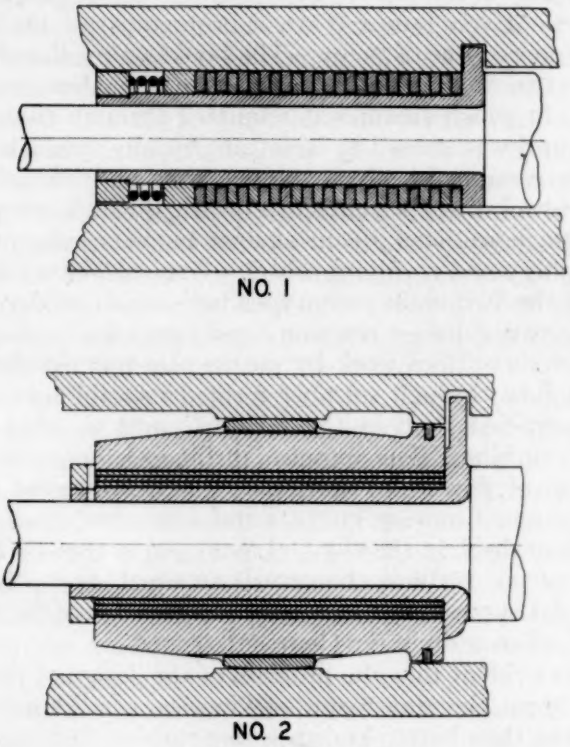
It is difficult to state the extent to which the prerenaissance turbines were reduced to practice. Many variations were proposed at about the time of the inception of the reciprocating engine development, most of them embodying reaction principles. Even James Watt, a protagonist of the reciprocator, proposed one of them. The books on medieval history refer to two fundamental forms—one the Hero engine of 130 B.C., in which steam was admitted through the shaft at the axis and was caused to issue tangentially through nozzles at the extremities of two revolving arms and the other, the Branca wheel of the seventeenth century, which comprised a nozzle which squirted steam against buckets mounted upon the periphery of a revolving wheel. Ancient history has thus given us the two main prototypes into which modern steam turbines are divided—"reaction" and "impulse." A reaction turbine element does work by means of a reactive force, the result of flow through suitably formed movable nozzles and was exemplified first in the "Hero," and in 1884 in the Parsons' turbine. The impulse turbine element does work by reason of flow from stationary nozzles directed against suitably formed moving buckets and was exemplified first by the Branca wheel, in 1888 by DeLaval, and in 1898 by Rateau.

No steam turbine, however, attained any degree of commercial success until the time of the work of Sir Charles Parsons, when a rapid development ensued.

It was evident that the problem of the design of the steam turbine, from the standpoint of kinetics, was identical with that of the then better known water turbine, but that much higher velocities would obtain as compared with an incompressible and a denser fluid, such as water. Therefore, the mechanical construction would differ greatly in the respect of dimensions of the fluid passages and the desirable bucket velocities. It was realized that the steam turbine, to be successful, must operate at higher rotative speeds than those at which anything had operated before. It was not then known that a rotor could be supported in bearings and revolved at the speeds which seemed necessary. Little or

nothing was known about the phenomenon of "whirling shafts," so a number of experiments were carried out. These resulted in the development of flexible bearings which permitted the rotor to go through a number of critical speeds without excessive vibration.

FIG. 1.



Early bearing construction.

Critical speeds of a rotor occur when its angular speed is equal to the natural frequency of one or other of the modes of lateral vibration of the rotor. At these speeds, violent vibrations will ensue. Supposedly, the shaft would rupture, if operation were continued, were it not for the damping effect of molecular friction of the material of the shaft.

The first successful bearing, shown on first illustration of Fig. 1, comprised a light sleeve outside of which was a series

of washers pressed together by a spring. Alternate washers fitted the housing and were clear of the sleeve. The remaining washers fitted the sleeve and were clear of the housing. The journal was centered by means of the wide washer. By this means, a slender shaft could tend to whirl, but the whirling would be damped by the friction between the washers.

This form of bearing was abandoned in favor of the form shown by the second illustration. It comprised the same light sleeve but surrounded with three light tubes having a few thousandths of an inch clearance between them. This clearance was supplied with lubricating oil. The journal of a comparatively rigid rotor could therefore take an eccentric path but be restrained to its geometrical center by the damping effect of a wave of oil film circulating around the bearing, the rotor tending to spin on its gravity axis.

The early Parsons' machines were of small capacity and operated at 18,000 r.p.m., so some form of construction which would attain results such as were obtained by one or other of these forms of bearings was a necessity.

The sleeve form of bearing was eminently satisfactory and was employed on both sides of the Atlantic until about 1904, when it was found that for the speeds and rotor constructions then in use, ordinary sleeve bearings without any provisions for flexibility could be employed.

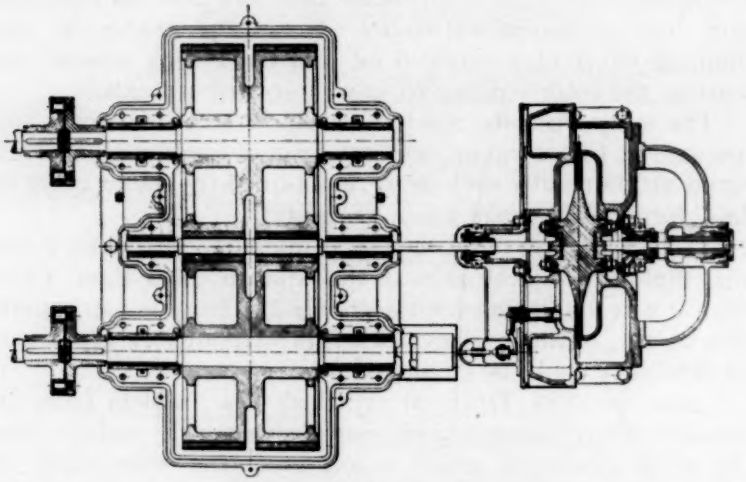
Later, in 1888, DeLaval attacked this problem from an entirely different angle. He had conceived a turbine (see Fig. 2) in which the whole steam expansion from initial to exhaust pressure was carried out in a single nozzle or group of nozzles which operated in conjunction with a single row of blades. To secure reasonable efficiency, the blades had to operate at the maximum possible velocity and consequently at a high rotative speed. Speeds of from 24,000 to 40,000 r.p.m. were selected. The turbine was geared to the driven machine by tooth gearing, sometimes driving two generators, the pinions operating between two gear wheels so that the pinion as a whole was not subjected to any lateral force. The turbine rotor comprised a single disc mounted on a long slender shaft, so the critical speeds were exceedingly low and the rotor would spin on its gravity axis when up to speed.

Obviously, such a construction could not apply to a multi-stage turbine where close clearances are a necessity.

It was DeLaval who invented one of the few turbine principles of modern times, viz., the divergent nozzle, by means of which steam velocities in excess of the critical velocity could be attained.

It is well known that steam issuing from an ordinary nozzle, without divergence, will not expand in the nozzle to a pressure less than about 56 per cent. of the initial absolute pressure, so that, no matter how much the down-stream pressure is further lowered, no greater exit velocity or weight

FIG. 2.



of flow is obtained, but by constructing the nozzle with a properly proportioned divergence beyond the throat, an efficient and complete energy transformation may be obtained corresponding to adiabatic expansion for any pressure range. The reason divergence is required instead of a "vena contracta," such as would be suitable for a water jet, is because after sound velocity is attained, the volume increments increase at a greater rate than the increments of the velocity corresponding to the energy transformation.

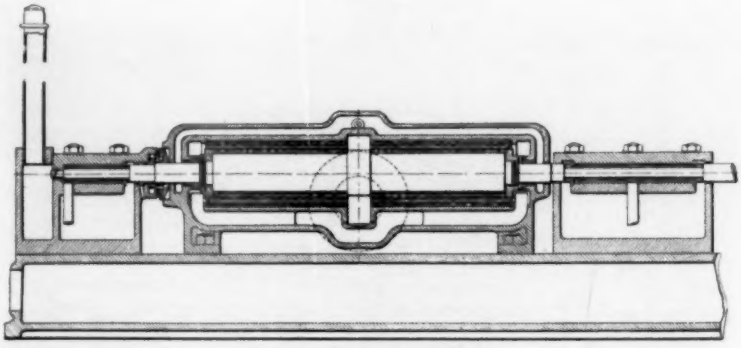
It was this invention that enabled DeLaval to construct turbines containing but a single row of blades and having a reasonable efficiency.

The DeLaval divergent nozzle is employed today in all turbine elements when the heat drop is sufficient to give supersonic velocity.

The earliest Parsons' turbines (Fig. 3) were simple double-flow reaction machines. The steam entered at the center and flowed in opposite directions to ports leading to a common exhaust opening. The steam path was embryotic.

Both rotor and stator were provided with brass rings with outwardly and inwardly extending flanges, in which saw slots at about 45° formed the blade passages. Improvement was made by bending the intervening metal into a curved shape.

FIG. 3.



Section of first turbine made, 1884.

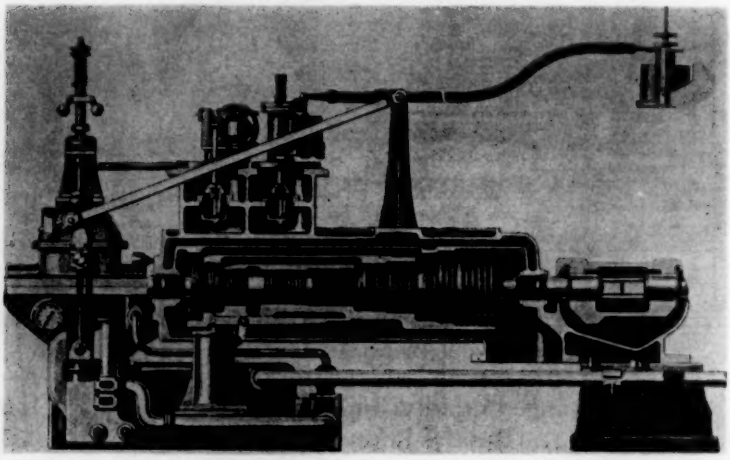
Designs changed rapidly, and in a decade reached the form shown in Fig. 4. Besides improvements in blade shapes, the diameter of the steam path was increased in steps to increase velocity as the steam volume increased.

There was another important development. Instead of admitting steam at the center, permitting it to flow through steam paths in opposite directions and exhausting at each end, the turbine was arranged single-flow, that is, the steam flowed through blading in one direction only, and in the other direction through a labyrinth packing called a "dummy." The labyrinth packing was arranged on the mean diameter of the corresponding blade path, so that the rotor would be without axial end thrust. Without the "dummy," there would have been end thrusts in excess of that which could

have been supported by any thrust bearing. By this means, the machine was shortened and leakage, the principal loss in reaction turbines, could be materially reduced. The double-flow construction is, however, still employed where large blade areas are required, as, for instance, in the low-pressure elements of large capacity compounded turbines.

Sir Charles Parsons first associated himself with Clarke, Chapman, Parsons & Co., as junior partner. This company was engaged in the building of ship auxiliaries, such as steam winches, windlasses, donkey boilers, etc., so that the first available market was for small electric generating sets for

FIG. 4.



shipboard use, and a number of them was installed on ships. This, it should be remembered, was in the early days even of electric light. The generators were direct-current and operated at speeds of the order of 18,000 r.p.m., and no small degree of resourcefulness was shown in their design. It is true that these generators would by no means measure up to the electrical standards of today, but electrical engineers of today would be appalled if required to design direct-current generators for such high speeds.

Sir Charles Parsons knew that the field of the steam turbine was in large power units but his partners resisted his

efforts to reach out into fields beyond those of small capacity electric generating sets. This resulted in disagreement and a dissolution of partnership in 1889, when a new company, C. A. Parsons & Co., was incorporated. By that time, about 300 turbines had been built ranging in capacity up to 75 kw. Unfortunately, the patents continued to be owned by the old company, and Sir Charles was obliged, by agreement, not to build parallel-flow turbines or drum-wound armatures as covered by his patents.

Sir Charles then devoted himself to developing some other form of turbine that would compete with the turbines built under his prior patents. He experimented with various forms of radial-flow turbines but was unsuccessful in equalling the performance of the parallel-flow machines previously built. A number of outward-flow, radial-flow turbines was sold, in which the shaft carried a number of discs, on one side of which were arranged annular rows of blades intermeshing with corresponding annular rows on the sides of diaphragms.

It is interesting to record that during this time, Sir Charles explored the possibilities of the "Hero" engine. Encouraging results were obtained with a single element, but attempts to improve efficiency by compounding elements in series were fruitless because of the friction of the arms in the denser fluid. In 1894, Sir Charles was able to re-acquire his original patents and any obligations concerning them, whereupon he at once reverted to his original parallel-flow reaction construction.

Up until 1895, the steam turbine as a practical machine was nearly unknown in the United States. Between 1833 and 1836, Wm. Avery of Syracuse had built some "Hero" turbines for driving saw mills. In one instance the turbine was reported to be more economical of fuel than the reciprocator it replaced. It is reported by Professor Sweet that in 1836 one of these turbines was employed to propel a locomotive, but its life ended in a ditch near Newark, New Jersey. These turbines were said to be objectionable because of noise and because of erosion on the back of the arm operating in the stream from the opposite nozzle.

Dow had sold a few ingeniously constructed radial-flow turbines that were employed by the Navy Department for spinning the flywheels of Howell torpedoes.

Two Swedish-built 300-hp. DeLaval single-disc turbines were imported in that year and installed in New York Edison plants. These particular machines are illustrated by Fig. 2. By this time, the evolution of the Parsons' turbine had reached the form shown on Fig. 4, and turbines as large as 500 kw., 3,000 r.p.m., had been supplied to power stations in England, all of which excited interest in the U. S.; in particular that of Mr. George Westinghouse, who, with characteristic foresight, acquired an exclusive license for the building of Parsons' steam turbines. An agreement with the Parsons Co. providing for the interchange of experience and information is still in force. About this time, or shortly thereafter, license agreements were entered into in Switzerland and France.

A 150-kw. English-built turbine was imported in 1896 and used for demonstration purposes. This machine generated alternating current at an odd frequency, so was useless for practical applications. It was later presented to Cornell University and was operated in the laboratory until the armature burned out. It is now reposing in the Museum of Useful Arts in New York.

A 120-kw. turbine driving a direct-current generator at 5,000 r.p.m. was the first Parsons' turbine built in the U. S. It was delivered to the Nichols Chemical Co., of Long Island, in 1896. It was short-lived. The commutation was unsatisfactory because of the high speed. After the shunt field coils were changed to permit operation at the lower speed of 3,600 r.p.m., it operated for several years in the Westinghouse Works as an exciter for alternating-current generator tests.

Some experimental machines, not of Parsons' type, were then built and tested under the direction of Mr. Westinghouse but without attaining improvement over the general principles practised by Parsons. It was not until 1899 that a commercial installation was made in this country by the Westinghouse Company. This was a plant for the Westinghouse Air Brake Co. and first comprised three 400-kw., 3,600-r.p.m. turbines driving 60-cycle generators. The first installation, with some later additions, operated successfully for about twenty-five years, when the plant was abandoned. Two of the generators failed early in life and all of them were changed

from revolving-armature to revolving-field machines, which then became standard construction for a.c. turbine generators.

A somewhat epoch-making turbine was supplied by the Westinghouse Co. to the Hartford Electric Light Company in 1900. The Hartford Co. has always been famous for its courage in installing novel machinery. Much later it was the first to install a machine operating under the principle of the mercury-steam cycle.

The Hartford turbine was designed largely under Mr. Westinghouse's direction, was of about 2,000 kw. and operated at 1,200 r.p.m. A test at full load with 155 lb. per in.^{2} steam pressure, superheated 42° F. and with 26.9-in. vacuum showed it converted 58.2 per cent. of the available heat into energy at the generator terminals. This was a remarkable result considering the time, the mediocre operating conditions, and the low rotative speed.

The complete expansion was carried out in a single casing and it had a greater capacity than any machine built up to that time. It did not, however, particularly shine from the standpoint of reliability.

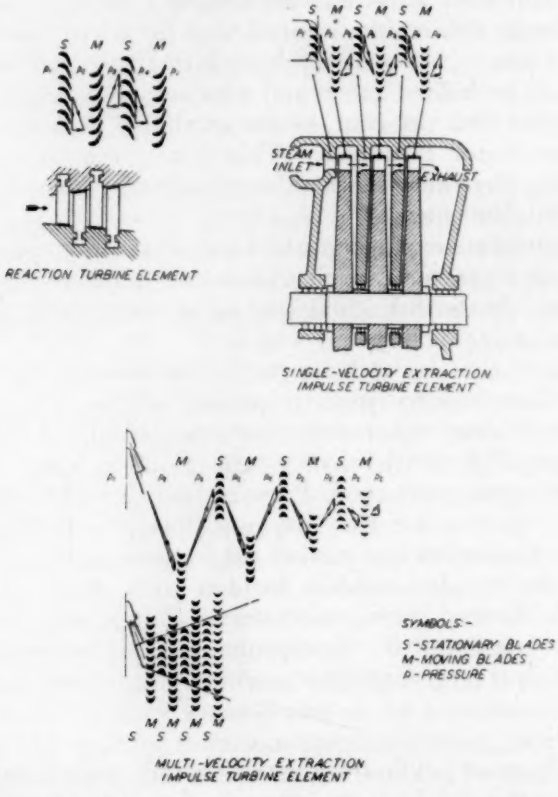
I believe that its at least partial success led the General Electric Company to enter the steam turbine field, which it did by acquiring rights under certain patents of Mr. C. J. Curtiss covering multi-velocity extraction elements.

In the same year, 1900, Parsons built a highly successful 1,000-kw. turbine for the City of Elberfeld (Germany), in which the expansion was carried out in two separate cylinders, which were coupled tandem fashion to a single generator. This was followed by a circumstance that is not uncommon in engineering practice. Europeans were so impressed by the idea of such a large capacity machine being constructed in a single cylinder, and we in this country were so impressed by the simplicity of construction and the reliability that could be obtained by multi-cylinder construction, that each abandoned his own practice and adopted the other's. The Westinghouse Company then built a number of machines of two-cylinder tandem construction, 750 to 1,000 kw. at 1,800 r.p.m., and 1,500 to 2,000 kw. at 1,200 and 1,500 r.p.m., which were highly successful from the standpoint of both reliability and efficiency.

By 1898, Mr. Rateau had become active in France in the development of an impulse type turbine comprising a series of alternate diaphragms and discs, the former provided with nozzle passages, the latter with a single row of blades.

So, by 1900, there had come into commercial practice the three main types of turbine elements that are illustrated in Fig. 5, that are now embodied in all stream turbines.

FIG. 5.



The types are:

1. Reaction, as proposed by Parsons.
2. Single-velocity, extraction impulse elements, as proposed by Rateau.
3. Multi-velocity, extraction impulse elements, as proposed by Curtiss.

It is perhaps appropriate that the differences in principle between these types of turbine elements be made clear and their respective shortcomings and particular application for each of them be pointed out.

In the reaction turbine, a pressure drop occurs in both stationary and moving rows of blades. For best efficiency, the pressure drop in the stationary blades is arranged so that the component of the velocity in the direction of motion of the moving blades is equal to the velocity of the moving blades. Steam therefore enters the succeeding moving blades without shock. The steam within the moving blades having the velocity of the moving blades, therefore contains the kinetic energy incidental to the expansion in the previous stationary row. The additional pressure drop in the moving blades is arranged so that the resultant velocity leaving the moving blades and that of the blades themselves will be in an axial direction relative to the earth. The illustration includes examples of velocity diagrams.

In pure impulse elements, the pressure drop occurs wholly in the nozzles with no pressure drop in the moving blades. The function of the nozzle is to transform the contained energy of the steam into kinetic energy, which is in turn absorbed by the succeeding moving blades. For best efficiency, pressure drops are selected so that the resultant velocity leaving the last moving blades will be in an axial direction relative to the earth.

The multi-velocity extraction element differs from the single-velocity extraction element only in the respect that greater pressure drops are employed in the nozzles. The steam enters the first moving row with a relatively high velocity which is redirected without further expansion or fall in pressure by stationary blades on to the next succeeding moving row and so on for as many velocity extraction elements as desired, or until the final velocity is sensibly axial in direction relative to the earth.

In practice, the "carry-over" from one stage to another of the energy contained in the resultant velocity leaving the moving blades, which may or many not be in an axial direction, must be considered in the proportioning of the succeeding element.

Single-row velocity extraction elements do not always operate as pure impulse elements. They sometimes have the attributes of the reaction element combined with them to a moderate extent, in which case some pressure drop is provided for over the moving blades, when blade clearances become important.

The best ratio of blade velocity to steam velocity, called "velocity ratio," differs in value for each of the three types. This ratio is useful for comparisons of designs, inasmuch as it is frequently compromised by lowering it for the sake of reducing cost or because of difficulties of construction, shaft deflection, etc., in which case the leaving velocities cease to be axial in direction.

There are a variety of arrangements of turbine steam paths employed, particularly in small turbines, which differ from these simple diagrams. All, however, embody one or other of these principles.

One type of successful reaction turbine which is worthy of mention, which differs in arrangement from those shown on the diagram, is of outward flow, radial type, developed by Ljungstrom in Sweden. In this type annular rows of blades are attached to the inner faces of two discs, the annular rows of blades intermeshing, the discs revolving in opposite directions, doubling the relative blade speeds. Each disc drives a separate a.c. generator, which revolve in opposite directions. The generators are tied together electrically, so the speeds of the discs are maintained equal to each other. This type has not been built commercially in this country, but remarkably high efficiencies have been obtained with machines built in Sweden, in capacities from 5,000 to 50,000 kw.

The multi-velocity extraction impulse element, as was first employed by the G. E. Co., comprised four velocity extractions per stage, as indicated on Fig. 5. The machines were disappointing in efficiency because of inherent losses in the later blade rows due to displacement losses, eddies, fluid friction, etc. The integrity of the jet probably was not maintained and the jet became scattered in its passage through the succeeding rows.

The General Electric Co. quickly reduced the number of

velocity extractions per stage to two. This type of turbine element is employed today in latest practice by both the General Electric and Westinghouse Companies, using one such element for the first high-pressure expansion and following that by other types of elements,—single-velocity extraction elements on the part of the General Electric Co. and reaction elements on the part of Westinghouse. In many instances of large capacity and where high efficiency is sought, the General Electric Company's machines are composed entirely of single-velocity extraction impulse elements. Similarly, the Westinghouse machines sometimes comprise exclusively reaction elements. The Allis-Chalmers Co., who became licensees of Parsons in 1904, builds mostly turbines that are exclusively of reaction type. The DeLaval Co. in this country employs generally single-row impulse elements.

The multi-velocity extraction impulse element seems at first sight to have attractive features.

1. A greater heat drop can be employed per stage with a given blade velocity, thus reducing the number of elements for a given heat drop.

Because energy is proportional to the square of velocity, the equivalent of *one* two-row velocity extraction element (Curtiss) is *four* single-row velocity elements (Rateau) or *sixteen* pairs of reaction elements (Parsons).

2. When employed for the first expansion, the parts subjected to the high pressure and temperature may be limited to a nozzle chamber and the nozzles, thus not subjecting the turbine casing to high pressure and temperature.

3. The impulse turbine element lends itself to fractional admission, i.e., the nozzles not occupying the complete circle. This would seem like a valuable attribute; the turbine might be designed for a low rotative speed because the steam path may occupy but a few degrees of the circumference of a large diameter. Nozzles might be employed of greater area and be more efficient because of a smaller ratio of perimeter to area. There are, however, serious losses involved in this practice. These are (*a*) fluid friction of the discs revolving in a more or less dense atmosphere of steam; (*b*) friction of the blades not moving in the path of the steam jet but in the more or less stagnant steam; furthermore, if the blades are

asymmetrical, they will do work by pumping the atmosphere of steam; (*c*) entraining the stagnant steam through partially filled blade passages at the ends of the nozzle groups; (*d*) displacement losses that are the result of stagnant steam within a blade passage that must be displaced as the blade passage comes into the path of the nozzles. This is a distinct loss because the velocity of the mixture corresponds to the sum of the momenta, each momentum being directly proportional to velocity whereas energy is proportional to the square of the velocity. This is why various attempts to reduce fluid velocities in turbines by entraining other heavier fluids by means of ejectors and the like, have always failed.

Designers of impulse turbines therefore employ complete admission whenever the circumstances permit, consistent with the nozzle passage not being so small that the fluid friction loss offsets certain of the losses just enumerated. It is, however, convenient to provide groups of nozzles for the first expansion, which are arranged to become automatically active one by one as load increases. In this manner, higher efficiencies may be obtained at fractional loads because full pressure may be realized at the nozzles at certain of such loads, but even then the designer will endeavor to provide for complete admission at the maximum load.

The reaction turbine has complete admission and has none of the disabilities incidental to fractional admission. Its principal disability is leakage over the tips of the blades. This occurs at the periphery of the turbine, while, in the case of the pure impulse turbine, it occurs only between the inner diameter of the diaphragms and the shaft. Where steam volume is large, so that the ratio of leakage area to total area is insignificant, the reaction turbine element should have higher efficiency. In the impulse element, there are two energy transformations, one transforming the contained energy of the steam into kinetic energy, which may be accomplished in the nozzle with high efficiency, the second absorbing that energy by means of the turbine buckets, which is accomplished at lower efficiency, whereas the reaction turbine comprises only nozzles.

The impulse element therefore seems to lend itself to elements where volumes are small and the reaction element where they are great.

A problem in steam turbine design of any type arises from the great increase of volume as the steam expands through the turbine. For instance, with a quite ordinary operating condition of 400 lb. per sq. in., superheated to 750° F., expanding to 29-in. vacuum, the volume increases in an efficient turbine about 350 fold. The problem is to devise, on the one hand, high-pressure elements that have efficiency, with the minute volumes involved, and, on the other, to devise elements at the low-pressure end having sufficient area of passage to handle the great volume involved with appropriately low leaving loss.

The lower the steam and blade velocities, the greater are the required areas; hence, the higher is the efficiency of blade passages and the lower the leakage losses, but, on the other hand, with lower velocities, the greater are the number of stages required for a given heat drop. The number of required stages will vary as the square of the velocities. These considerations of cost and practicability of construction lead the designer to the highest possible velocities consistent with the steam volumes involved. In any series of elements of any one kind, it is usual to increase the blade velocities progressively as the steam volume increases.

For these reasons, in the case of machines of large capacity, the steam expansion is sometimes divided between two casings, each driving a separate generator at a different rotative speed, a synchronous speed being selected for each of them that is appropriate to the steam volume passing the particular element.

Take the case of two geometrically similar turbines, the one having twice the linear dimensions of the other. The larger of the two would operate at half the speed of the other and have the same blade speed and the same ratios of critical speeds to running speed. The areas for flow would be four times as great; hence, it would have four times the capacity. The weight, however, would be eight times as great. Therefore, on this basis of geometric similarity, should we, in order to design a turbine of four times the capacity of some other one, and in order to accomplish this, reduce the speed to one-half, the weight per unit of output would be doubled. This is only academically true, for geometric similarity would

not obtain in designing from one capacity to another. The rule, however, shows the economic desirability of designing for the highest possible rotative speed. If, in producing a design of greater capacity than another, it is necessary because of volume, to reduce rotative speed, the weight per unit of output will increase in some proportion inversely as the speed. The best turbine, from the standpoint of the purchaser and seller alike, is the one which has the greatest capacity at a given speed consistent with there being no inordinate cost because of designing for high stress. This phase of the problem obtains at the low-pressure end where steam volumes are greatest. The greater the volume that can be arranged to flow at exhaust pressure, the easier becomes the problem of obtaining efficiency of the high-pressure elements. Hence, during the last several years, engineers have directed attention to obtaining the greatest possible low-pressure blade areas with a given rotative speed. They have increased the speeds of the tips of blades from about 400 to 1,250 ft. per sec. during the period of U. S. practice.

A comparison of the true capacity of condensing turbines which operate with a common vacuum may be made by measurement of the annulus occupied by the last row of blades, which is a truer comparison than the name plate.

The ability of a turbine to make use of a given heat drop may be expressed by what is called the "blading constant." It is proportional to the value given in the equation:

$$k = \Sigma(D^2N) \times n^2,$$

in which k = the blading constant,

D = the mean diameter of any group of elements of the same diameter,
n = revolutions per minute,
N = the number of elements in any one group expressed in terms of reaction elements.

1 2-row impulse element = 4 single-row impulse elements = 16 pairs of reaction elements.

The number of stages in a given turbine is no measure of capacity. Capacity is measured by area.

Any increase of weight of steam may be caused to pass a given blade passage by raising the up-stream pressure, but this involves leaving loss, or perhaps even incomplete expansion, but inasmuch as the cost of the whole machine is profoundly affected by the area of the last annulus, and since energy cost is made up of both operating cost and fixed charges, there are cases where it is appropriate to lower efficiency by increasing leaving loss in order to reduce capital cost, particularly when a machine is expected to operate with low load factor. It is a simple matter to increase the capacity of a given high efficiency design by at least 100 per cent. by merely providing larger high-pressure elements with practically no increase in cost except that due to larger valves and steam pipes and the larger generator.

Turbine performance may be expressed in several ways, but none of them permits a direct comparison between turbines operating under differing operating conditions. Elements operating in gaseous steam naturally have a higher efficiency than those operating in steam containing moisture, although there may be equal available work in the heat drop involved.

Comparisons are rendered more meaningless by the practice of extracting partially expanded steam from a number of stages of the turbine and condensing the extracted steam in a series of stages of feedwater heaters. By these means, the Rankine cycle is departed from and the Carnôt cycle to some degree approached. The extracted steam alone operates with a thermal efficiency of 90 to 95 per cent. because its principal heat component, i.e., the heat of evaporation, is returned to the system instead of being thrown away with the condenser cooling water. The energy developed in the turbine by the extracted steam may be regarded as "by-product" power.

This system of feedwater heating by extraction, while only introduced commercially in about 1922, was, by the way, actually invented and patented by Ferranti about 1905. Ferranti invented ahead of his time. He actually built a turbine not only with some stages of feedwater heating, but also some stages of steam reheating, so that the whole expansion was with highly superheated steam. His turbine

failed utterly, not because his principles were unsound but because he constructed his casing of cast iron, which grew and warped out of shape. The phenomenon of growth of cast iron with high temperature was then unknown.

A common expression of performance is the weight of steam per unit of output, which is only of value for comparison when all operating conditions are alike. Any turbine may have its performance expressed as a heat rate, which reflects the work of the boiler, and hence the fuel cost, which most concerns the operator. For a turbine without extraction for feed heating, it is customary to charge the turbine with the heat supplied and credit it with the total heat in the saturated liquid corresponding to the exhaust pressure. If steam is extracted for feedwater heating, the turbine is credited with the total heat as measured leaving the final heater. There is, therefore, a vast difference between these two cases when so expressed, even though they concern the same turbine. This is because of the change in type of heat cycle.

That which reflects more closely the quality of the turbine, unrelated to anything else in the plant, is known as "engine efficiency," formerly called the "Rankine Cycle Efficiency Ratio." It is the ratio of heat converted into work and delivered by the actual machine, to the heat theoretically available by adiabatic expansion from a given initial pressure and temperature to a given exhaust pressure. Even these will not give exact comparison because, as stated before, if the expansion reaches sub-saturation steam conditions, the same turbine would show a higher engine efficiency with higher initial superheat.

The progress that has been made in performance in this country from the standpoint of efficiency and the causes which have brought it about, including a review of some of the difficulties which had to be overcome, will be reviewed, but it should be understood that from here on, this discussion refers principally to the Westinghouse Co.'s experience.

The thermal efficiency, exclusive of boiler losses and auxiliary machinery, from the inception of activity in this country, has been increased from about 11.8 to 38.0 per cent. (29,000 to 9,000 B.t.u. per kw. hr.).

The thermal efficiency of the overall steam-power station

has been similarly increased from about 11.5 to 28.5 per cent. (30,000 to 12,000 B.t.u. per kw. hr.). In this relation, feed heating by extraction has had influence.

The engine efficiency of the turbine, including generator losses, has been increased from about 54 per cent. in machines of 300-kw. capacity to 85 per cent. in machines of 50,000 kw., or larger. Because the state of diminishing returns has been reached, it is probable that there can be but minute improvement in this ratio. Further economies must be the result of causes other than improvement in the engine efficiency of the turbine itself.

A progression of design changes involving the steam path, together with their objectives, will be briefly shown.

FIG. 6

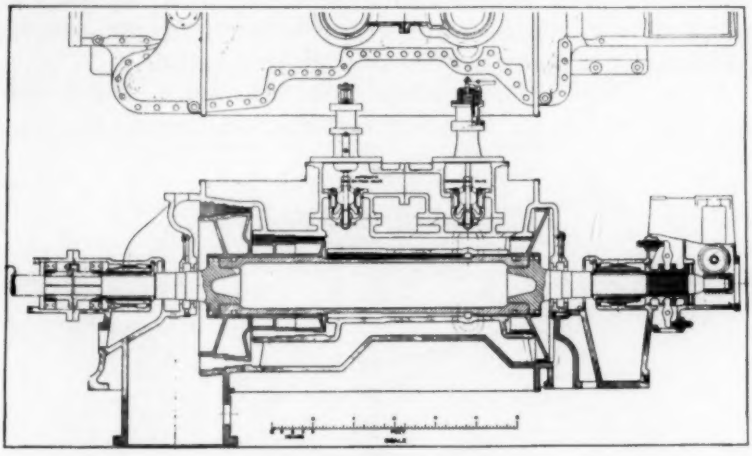


Figure 6 shows an early type, which, except for details, is in close accord with the principles enunciated by Parsons and is exclusively of single-flow reaction type. The blade path is conveniently arranged on three diameters, on each of which the areas progressively increase. Three "dummies" are provided having the same diameters as those of the mean blade paths, so that with equal pressure drop over adjacent moving and stationary blades, the turbine will operate without end thrust. Pressure is equalized between the steam path

and the balancing pistons by means of pipes or passages connecting the cavities where the steps in diameter occur.

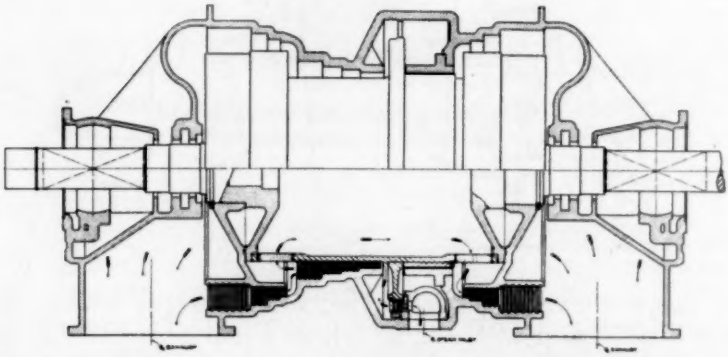
At normal output, or at the most economical output, steam passes the whole turbine. At overloads, some steam is bypassed to the second step by the opening of the secondary valve.

This general type was employed until about 1909, in capacities up to 500 kw. at 3,600 r.p.m., 1,000 kw. at 1,800 r.p.m., 3,000 kw. at 1,200 or 1,500 r.p.m., 7,500 kw. at 750 r.p.m.

These rotative speeds were so low that leakage ratios were high in the high-pressure portion, and compromises had to be made in velocity ratios for reasons of mechanical construction. The engine efficiencies obtained would hardly bear comparison with present-day practice. Notwithstanding, the efficiency of these early machines was superior to that of any competitive prime mover. Temperatures were comparatively low, so there were not many difficulties from that cause.

A new type of construction came into use in about 1909, as shown on Fig. 7. The objective was to eliminate the small

FIG. 7.



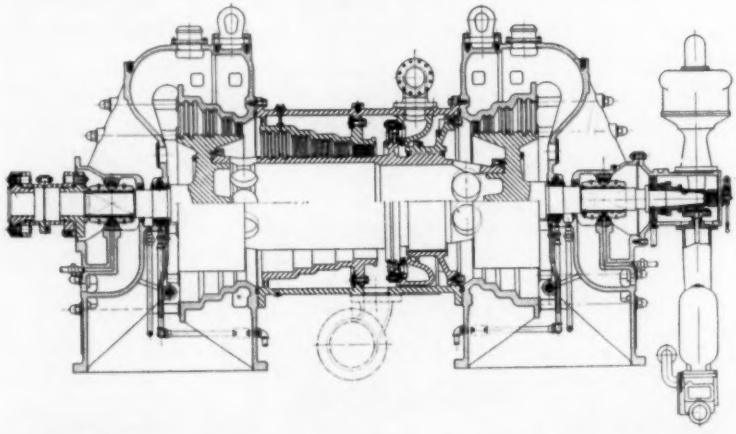
group of small reaction blades on the small diameter of the first expansion of the previous design (Fig. 6), which occupied about three-quarters of the length of the steam path and did but 20 or 25 per cent. of the total work, and in which, because of the small steam volume, and hence small blades, the leakage ratios were high, and to substitute for this portion a two-row

impulse element having high velocity in which some fraction, such as 20 per cent. of the total work, would be carried out. With this substitution, the length of the high-pressure portion was materially reduced. While the inherent efficiency of the impulse element was lower, it was without leakage. By this time, the steam temperatures had increased, so advantage could be taken of effecting a material reduction of pressure and temperature in the first nozzle group, to which the main casing was not exposed.

A further object was to arrange the low-pressure elements double-flow, so that ample low-pressure blade area could be obtained with conservative blade speeds and stresses.

The steam discharged from the impulse element passed through a series of single-flow reaction elements balanced by a labyrinth packing, after which the steam was divided between the two low-pressure elements, one-half of it passing through the interior of the drum-like rotor.

FIG. 8.

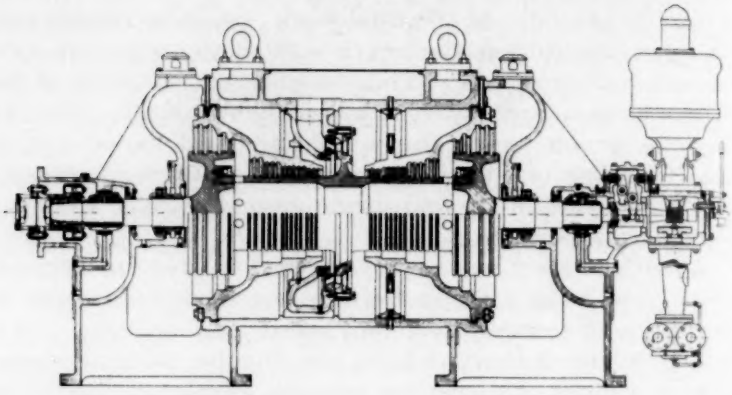


A later development of the same type is shown on Fig. 8. In this design, higher blade speeds, r.p.m., and velocity ratios were employed.

Some of the machines were arranged completely double-flow except for the impulse element, as shown on Fig. 9.

This design eliminated any labyrinth or dummy which, in the previous single double-flow designs was remote from

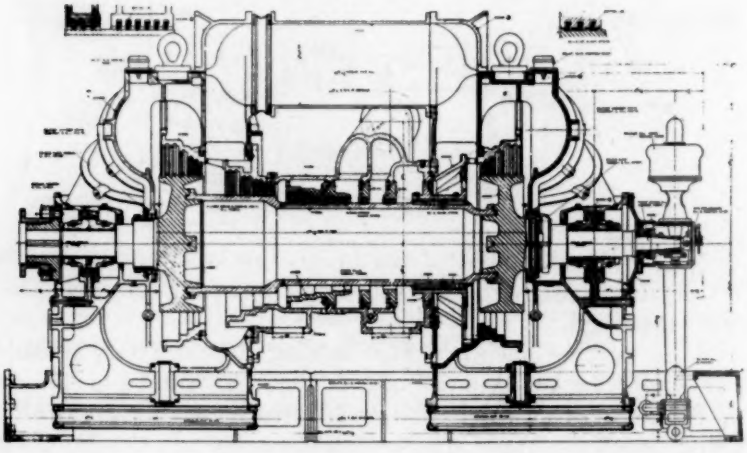
FIG. 9.



the thrust bearing and because of varying linear expansion was sometimes troublesome because of interference between the axial intermeshing labyrinth strips. This difficulty was subsequently overcome by the substitution of radial clearance labyrinths by which, while leakage through the labyrinth was increased, a considerable latitude of axial position was permitted.

Some large capacity machines of 35,000 kw. were built completely of reaction elements (shown in Fig. 10), with the

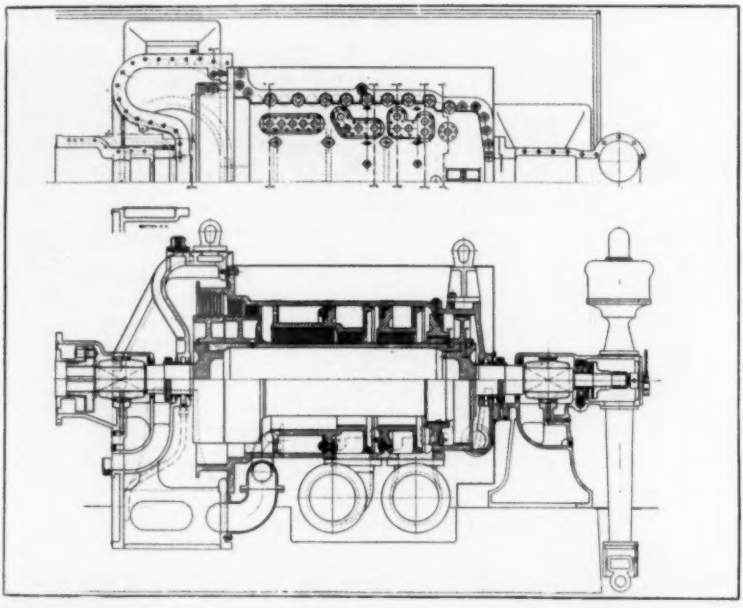
FIG. 10.



object of attaining higher efficiency since greater high-pressure steam volume was available. In this case, the area of the interior of the drum was not large enough to pass half the steam, so an exterior connection was provided.

The first cross-compound machines were put in service in 1914. In this type, the expansion was divided between two separate casings, each driving separate generators. The total capacity was 30,000 kw. for 25-cycle service. The high-pressure element operated at 1,500 r.p.m., and is shown on Fig. 11. It was a simple single-flow reaction turbine of

FIG. 11.



well-tried and conservative design. The steam volumes and r.p.m. were such as to permit generous blade areas.

The low-pressure element operated at 750 r.p.m. and is shown on Fig 12. It shows simple double-flow reaction. elements with a last row mean blade velocity of but 400 ft. per sec.

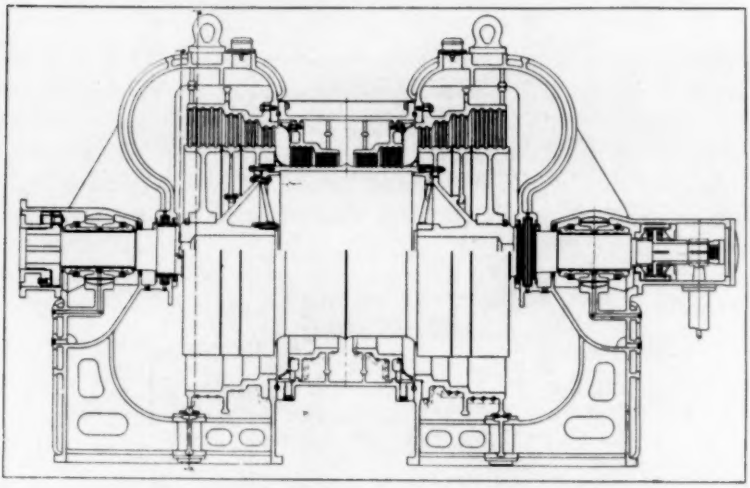
These machines had a greater capacity than any built until that time. They were too costly and ponderous for a modern

market, but they made a record in efficiency. They are still in operation at the plant of the Interboro Rapid Transit Co., New York, and are believed to hold a higher reliability factor than any other machines.

Later, turbines of this general type were built for 60-cycle service, operating at 1,800 and 1,200 r.p.m., respectively, and had capacities ranging from 30,000 to 110,000 kw.

Generally, the trade has preferred turbine elements driving a single generator. However, no difficulty in operation has been experienced because of the cross-compound principle

FIG. 12.



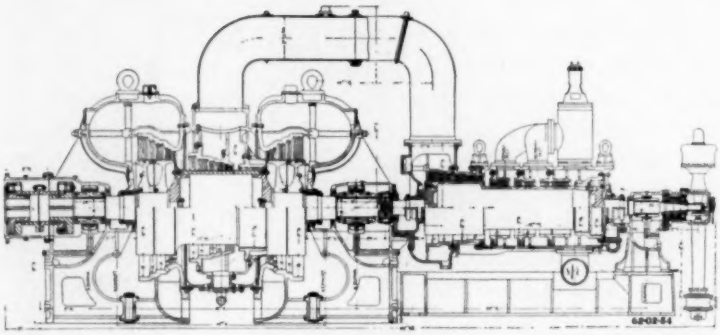
Sectional plan DeLaval Turbine, 300 HP.

involving two or more generators. They may occupy more space, but the system is conducive to simplicity and reliability.

Since 1917, a number of tandem machines has been built of the general type shown on Fig. 13, having a capacity of from 35,000 to 50,000 kw., at 1,200 and 1,500 r.p.m. A few small capacity machines of this type were built as early as 1903. to which reference has been made.

The latest Westinghouse turbine, having a capacity of 165,000 kw. at 1,800 r.p.m., is of this general type and is shown on Fig. 14. It is being built for the Philadelphia

FIG. 13.



Electric Co. It is expected to show an unprecedented engine efficiency. The purpose of the wide stationary blades in the low-pressure section is to permit the hubs of the discs to have requisite strength.

The openings from the steam path between each of the last two blade rows is for the purpose of withdrawing moisture. In this instance, moisture and some steam with it are drained to small feed-water heaters.

Experience in the design of blade fastenings and rotors, also the development of stronger materials, have permitted

FIG. 14.

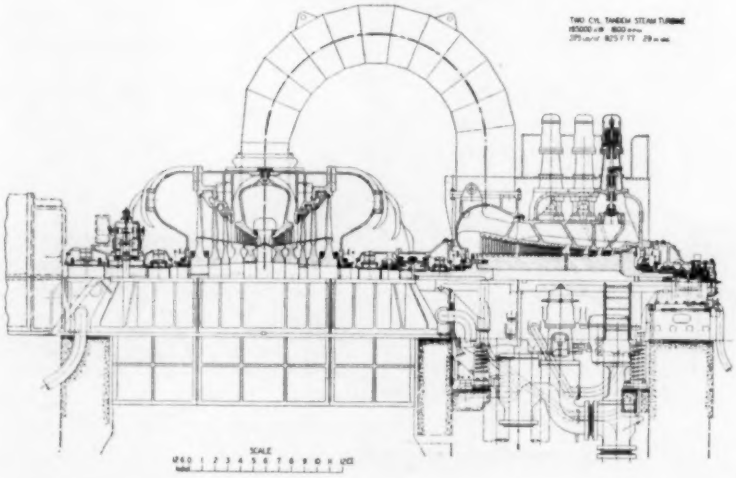
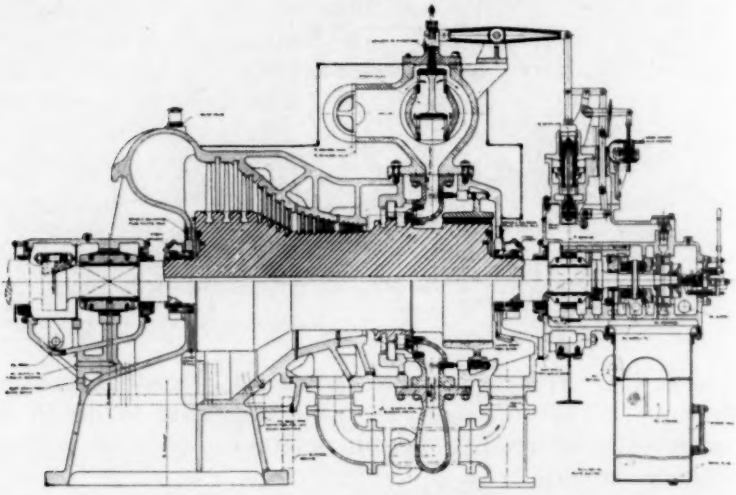
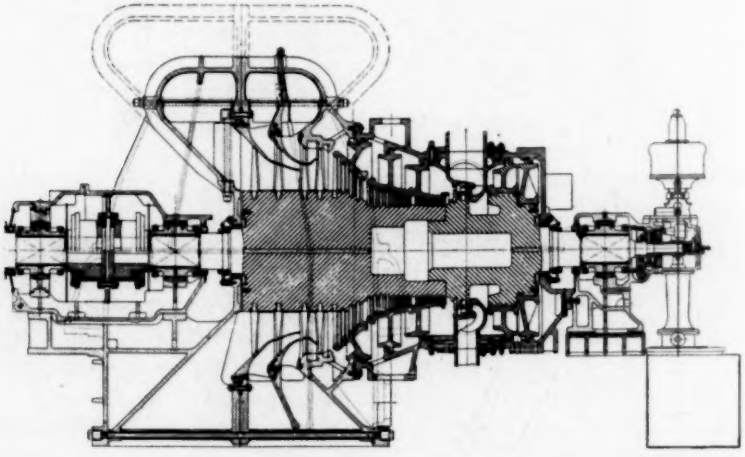


FIG. 15.



progressive increases in low-pressure blade speeds, so that double-flow, low-pressure elements came to be discarded except for compounded machines of large capacity. This resulted in the design of machines of the general type shown on Fig. 15, of which a great number has been sold. This particular machine is one of 6,000-kw. capacity, 3,600 r.p.m.

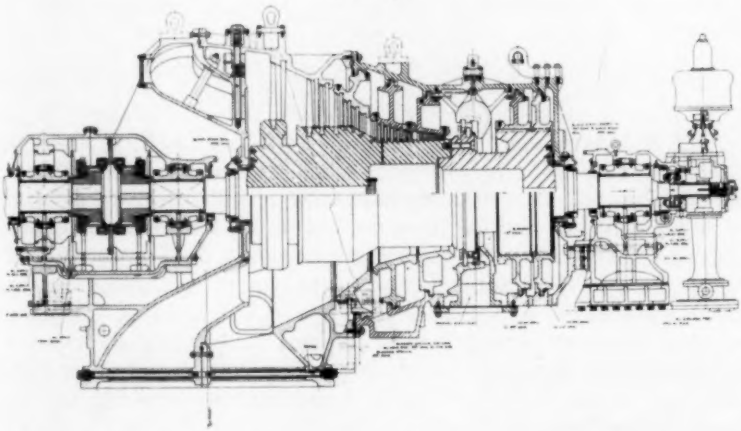
FIG. 16.



and is the machine of which there is a full-sized model in the Franklin Institute Museum.

In 1922, a line of machines was developed of 30,000 to 45,000-kw. capacity, as shown on Fig. 16, which shows another means of increasing low-pressure blade areas without increasing blade speed and stress. This multiple exhaust system was invented by Baumann of England and is another of the few modern inventions of steam turbine principles. By its means, with the three last blade passages as shown, twice the area is obtained than with a single last row of blades of the same dimensions. The problem of design was to arrange the blade passages of the inner tier so that the steam in passing would do no work on the blades or the blades do no work on the steam. A number of successful machines has been built with this multiple exhaust blading, but it was concluded that a higher leaving loss was a lesser evil than the losses incidental to the steam passing the inner tier, besides which the construction is costly. It was therefore abandoned and the type shown by Fig. 17 was substituted. This is in

FIG. 17.



substantial accord with present day practice within the limit of capacity to be obtained with a single-flow, low-pressure element. For greater capacity, compounded turbines with double-flow, low-pressure elements are employed.

(To be continued)

Monel Metal of High Strength.—We are informed that after twelve years of research and development, engineers of the International Nickel Company have produced a new type of monel metal which combines the strength of alloy steels with the corrosion resistance of regular monel metal. This new alloy, known as K Monel, differs from the usual type in that it contains about 4 per cent. added aluminum and fractional amounts of other elements. It is readily heat treated and its fully hardened condition shows Brinell values above 350. Its tensile strength runs higher than 160,000 pounds a square inch.

C.

Celluloid is Used by Pipe Line to Combat Corrosion and Stress.—L. E. BREDBERG. (*Oil and Gas Journal*, March 14, 1935.) For combating corrosion of pipe lines, pipe line companies are investigating vulcanized rubber coating and celluloid. Though data obtained after a year's use of celluloid by a large western company is not entirely sufficient, it is believed that this material is a very effective preserver. The proper name of the celluloid shield is "cellulose nitrate plastic" to distinguish it from acetate plastic. Its trade name is Pyralin and it comes in layers of ten one-thousandths of an inch thick (can be obtained in any thickness up to twenty one-thousandths of an inch). It is shipped in rolls the layers of which are 17 inches wide. Layers are cut in two for wrapping 6 and 8 inch pipe; 20 inch layers used for larger pipe. Since Pyralin is inflammable it is stored in a dark, well ventilated warehouse; it flashes at 525° F; its tensile strength is 8,000 lb. per sq. in.; it is brittle at −20° F. and softens at 220° F., beginning rapid decomposition at 325° F. When softened it will expand 5 per cent. by volume and when hardening it will shrink 12 per cent. by volume; this shrinking does not crack the material, which acts like stretched rubber. Atmospheric pressure does not cause the material to deteriorate, but the exposure to sunlight, which contains ultra-violet rays, will break it down. A softening compound (alcohol, ethyl acetate and water) is used in bringing the material to pliable state necessary for placing it over collars and other raised places on the line. A Pyralin quick-setting cement is applied by a hand-wielded brush to the edge of the roll of wrapping as it is spiraled around the pipe.

R. H. O.

A TESTING METHOD FOR MEASURING THE RELATIVE FORCE OF THE INDIVIDUAL BLOW OF HIGH SPEED HAMMERS AND THEIR FREQUENCY.

BY

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In the construction of high speed hammers, especially those of the pneumatic type, it is of particular importance to determine exactly the physical work they are capable of doing, i.e. the effect of the force of the individual blow of the hammer multiplied by the number of strokes per time unit. Only when this is known is it possible to time the hammer to its highest efficiency, and thus do a definite amount of work with the least energy consumption or do this work in the shortest possible time for a given energy expenditure.

For a given power balance, the conditions for maximum output at the actual rivet end must be chosen properly. Such factors as the length and diameter of the barrel must be considered. Furthermore, the weight and size of the oscillating piston, its frequency, the optimum air pressure, the influence of the barometric pressure, and many more factors are of importance for calculating the best speed and working conditions for any given load.

The piston of a riveting hammer operates on the average of one thousand (1,000) blows per minute, while small scaling hammers may go as high as four thousand (4,000) strokes per minute. Under these conditions it is difficult to measure the force of the individual blow and the number of strokes per time unit.

The present test methods used have failed to give specific data and are not reliable. In one form of test, a tapered, polished punch is driven for twenty (20) seconds into a pot of lead, the depth thus attained being taken for a comparative power reading. In another method—the bar drive test—a highly polished bar, about twenty-four (24) inches long and

one and three-quarters ($1\frac{3}{4}$) inches in diameter, is driven through a bronze bushing. In the second method the bar is first warmed up by driving it repeatedly back and forth through the bushing, with the hammer to be tested, until the number of seconds required to drive it from one end to the other becomes constant. This time is compared with the number of seconds required by a standard hammer, known as the master hammer, to accomplish the same task.

While this method gives a comparison between two hammers, these tests are not entirely reliable since considerable variation may be found in a series of tests, even with the master tool. Moreover, no reliable conclusion can be drawn as to the number of blows per minute if calculated by the standard method, i.e. from the air pressure and air consumption only. The accuracy of such a determination is influenced by such factors as barometric pressure, the temperature, the humidity, etc.

The test method described in this paper was therefore devised for comparing directly the effect of each individual blow of one hammer with another, giving objective results and going up to the highest speeds. In addition, a reliable means is hereby given for recording the number of strokes per time unit.

This new method can be considered as a reversion of the dynamic ball pressure hardness test, such as the one devised by Brinell. However, while in the latter the force upon the ball is constant and the hardness of the material tested is unknown, in this instance *a conclusion is drawn as to the unknown force that delivered the blow, from the known hardness number of a bar and the known diameter of the ball.*

While this new test is sufficiently simple that it can be used in actual production and field work, it should be stated here that for making absolute measurements certain precautions must be taken. For this latter purpose, the same conditions should be maintained that are used in the standard Brinell test.[1] In this connection, it should be noted that no general conclusion should be drawn as to the true acting force as such, from a comparison between the ball impression obtained under the quasi-stationary conditions of the Brinell

[1] See A. S. T. M. Designation E 10–27.

Test and the impression made dynamically within a relatively short time interval.

However, inasmuch as only the *effect* of the operating hammer is of particular engineering importance, it is permissible to compare this effect resulting from a dynamic blow with the effect resulting from the quasi-stationary application of a load during a relatively extended period of time.[2] Although the properties of elasticity, ductility, etc., enter into the dynamic test in addition to the displacement of material proportionate to the hardness of the test strip, they do not reduce the value of the test mentioned in this paper for the same reason. Again, only the integrated value of all these side effects is of importance as shown in the actual deformation, for example, of a rivet head per unit of time or the consumption of energy per foot of hole drilled.

It is therefore permissible to state the *readings taken in terms of a relative, quasi-stationary load*. This means that the actual effect of the hammer, working under its specific conditions, is compared directly to the same effect that would be obtained if a static load of x kilograms was exerted upon the same ball and the same test strip.

The amount of permanent deformation obtained in the testing material is taken as a measure of the original force applied to it by the blow. The force is estimated by a comparison with a series of deformations secured by impressing a ball of steel 10 mm. in diameter, slowly and continuously, over a period of more than 30 seconds, upon the test specimen.

In the Brinell test it is known that a hardened steel ball of a given diameter makes an impression upon the metal or material with which it is brought into contact when pressed with a standard force upon a smooth, flat surface of the material. The indentation varies in area and therefore in

[2] Under quasi-stationary conditions it is the general custom to neglect such factors as ductility (drawing properties) toughness, brittleness, elasticity, tensile strength, temperature of the test specimen, etc., which are often a direct function of the Brinell number. It is even possible to determine the hardness number of a given material upon consideration of one of the other factors proportionate to it, for instance, the elastic properties of it (rebounding hammer). If the force of deformation is applied to the test strip over a relatively short period only, they come again into consideration. The characteristics of materials at great relative speeds are somewhat different from quasi-stationary conditions.

depth and diameter. This depth and/or diameter is brought into relation with the standard hardness of the material.

If P is the pressure in kilograms,
D is the diameter of the ball,
d is the diameter of the indentation, and
Δ is the depth of the indentation,

then according to the Brinell equation, the hardness number N, for a known load, P, may be written in the form of the following equation (1):

$$N = \frac{P}{\pi D \Delta} \cdot \tag{1}$$

If D and d are given, Δ can be determined from the following:

$$\Delta = \tfrac{1}{2}(D - \sqrt{(D^2 - d^2)}, \tag{2}$$

as is obvious from equation (1).

In substituting (2) in equation (1) we may say:

$$N = \frac{P}{\pi D \Delta} = \frac{P}{\frac{D\pi}{2}(D - \sqrt{D^2 - d^2})} \cdot \tag{3}$$

The stress applied to the test specimen must hereby be in excess of the elastic limit of the latter.

The relation between the load, P, and the depth of the impression (which is a function of the inverse square of the diameter d) is constant for any one metal and one ball size.[3] This has been established for the quasi-stationary conditions and seems to be true within the experimental limits given in Table 1.

TABLE 1.

Quasi-Stationary Load P in kg.

Diameter D of the Ball in Millimeters.	$\frac{P}{D^2} = 1.$	$\frac{P}{D^2} = 5.$	$\frac{P}{D^2} = 10.$	$\frac{P}{D^2} = 30.$
D = 1	1	5	10	30
D = 2	4	20	40	120
D = 5	25	125	250	750
D = 10	100	500	1,000	3,000

[3] Devries, *Proc. Am. Soc. Test. Mat.*, 1911, p. 725.

The definition of the Brinell hardness number is the quotient of the applied load divided by the area of the surface of the impression.[4]

If the hardness number of the material is known (this can be determined by any of the usual Brinell, Shore, Rockwell or other hardness tests) and the diameter of the sphere is known, then the equation (3) may be written in such a form that it is possible to determine the force applied to the sphere:

$$P = N\frac{\pi}{2}D(D - \sqrt{D^2 - d^2}) = N\pi D\Delta. \qquad (4)$$

From the three known data, the diameter of the ball, the diameter of the indentation and the hardness number, it is possible to determine the force necessary for making this impression.

In addition, it is possible to calibrate a testing material of constant Brinell number so that we know the applied pressure directly from the diameter of the indentation when using a ball of known size.

In equation (4), the expression

$$N\pi D \text{ is constant } (= C). \qquad (5)$$

Hence:

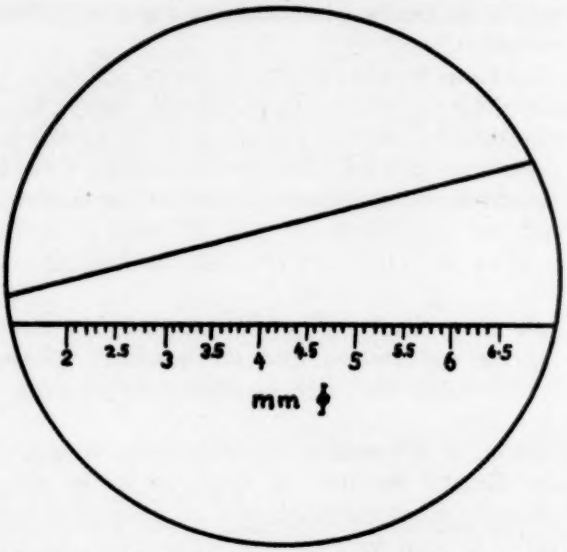
$$P = \Delta C. \qquad (6)$$

In this equation (6), there is only one variable, Δ, which can be determined easily with an exactness of better than one-tenth of one millimeter by measuring the diameter of the hole with one of the known reading devices. For increasing the exactness, the spherical area should be calculated from the average diameter of the impression, obtained by taking at least two readings at right angles to each other and not from the depth of the impression.

A simple and effective device for such measurements, for instance, is a reading glass showing an enlarged picture of the impression, together with a graduated scale of the type shown in Fig. 1 within the field of vision. A direct reading with an exactness of better than one-tenth of one millimeter can be taken if the two lines which are inclined toward each other are tangent to the circle of the impression. The smaller the

[4] Definition according to the British Standard Tables of Brinell Hardness Numbers (No. 240, 1926).

FIG. 1.



Field o view of reading glass for the exact determination of the diameter of the impression.

angle between the two lines, the greater the exactness. It is possible to calibrate the reading glass directly in terms of the relative load with reference to each standard test bar of known hardness and for each ball diameter.

In the following table—No. 2—the values of the relative

TABLE 2.

An indentation of d millimeters diameter made upon a test bar of a Brinell hardness number $N = 200$ corresponds to a value P of the relative load in kilograms:

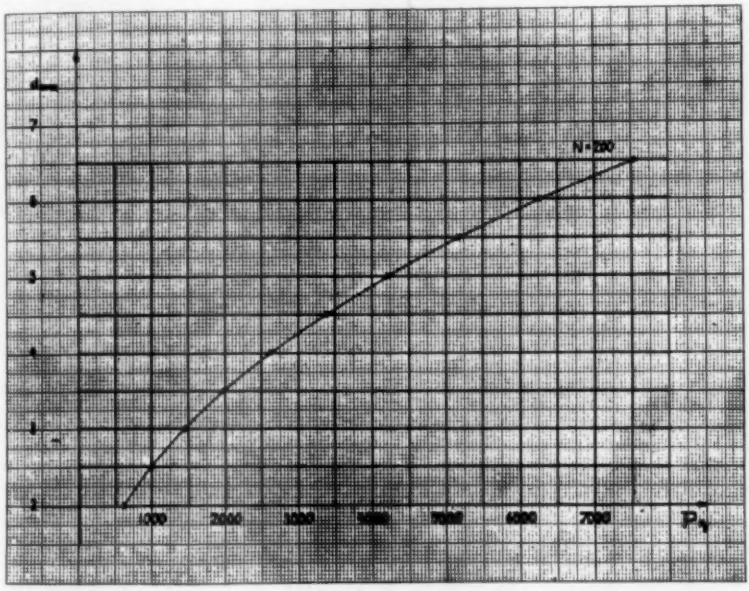
$$N = 200,$$
$$\frac{N\pi D}{2} = 3141.59.$$

d mm.	$Pkg = \frac{N\pi D}{2}(D - \sqrt{D^2 - d^2})$.
2	635
2.5	999
3	1,448
3.5	1,986
4	2,620
4.5	3,392
5	4,210
5.5	5,176
6	6,283
6.5	7,542

load have been computed for a hard steel ball of ten (10) millimeter diameter and a standard test bar of a Brinell hardness number $N = 200$.

In the accompanying figure—No. 2—these values have been plotted in a rectangular coördinate system and the connecting curve has been drawn. The relative loads, P, referring to each individual diameter, d, can be found readily on this graphical representation, including interpolations between the values of Table 2.

FIG. 2.



The values of the relative load P for a standard bar of $N = 200$ and a ball of 10 millimeter diameter.

Analogous curves can be constructed for impressions upon bars of a different hardness from the one depicted above, or for balls other than ten millimeters in diameter. They would become of importance if the relative load to be measured is below 635 kg. or above 7,542 kg.

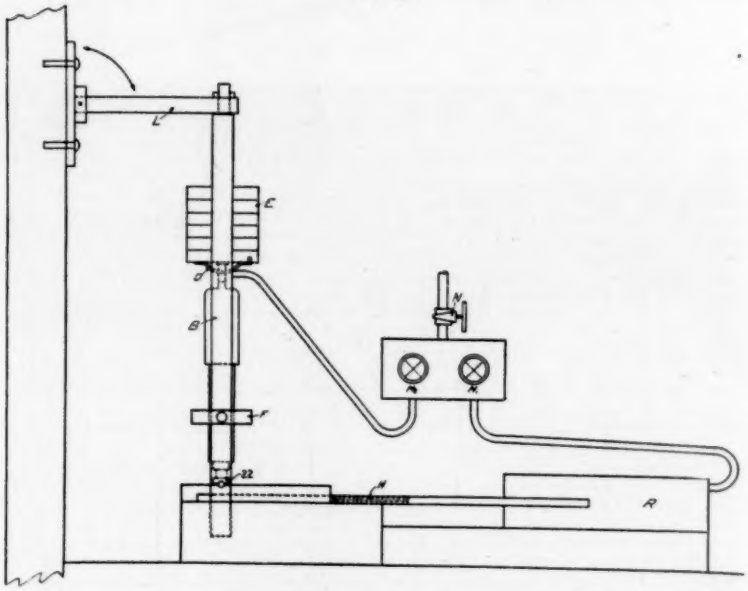
The following gives the principles for a technical construction for the purpose of testing air hammers.

A riveter is held vertically in position by two standing

supports, *A* and *B* (which may be anchored in the wall by a removable holder *L*). (See Fig. 3.) They are spaced sufficiently far apart and are high enough that various sizes and type of hammers can be placed between them.

These rods, *A* and *B*, are of a round cross section which facilitates certain finer adaptations and experiments that may be considered necessary for the calibration of the apparatus later on.

FIG. 3.



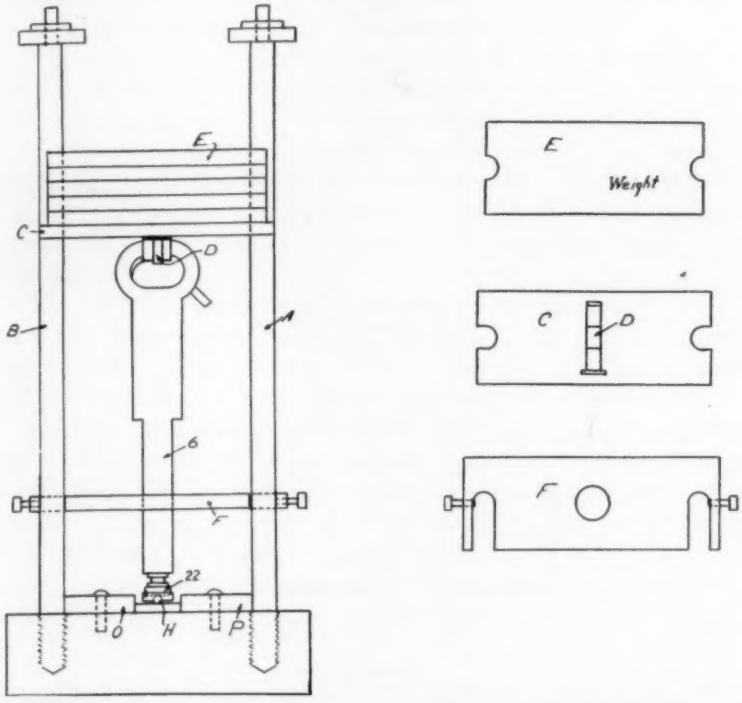
The handle of the hammer is attached to the plate, *C*, by the strap, *D*. A piece of rubber is wound around the handle. The same strap holds the valve control of the air hammer so that the switch remains open. The pressure is regulated from a separate valve, M_2 (Fig. 4).

A number of weights is placed upon the plate, *C*. Their shape is shown under *E*. The number of weights is important for the determination of the optimum load for the different types of hammers. Since both the speed of the hammer and the diameter of the indentation change with the pressure upon the hammer, the optimum pressure with which a hammer should be pressed upon the material to be treated, can be

determined by this method from the product of the relative force times the number of strokes per time unit. If this product reaches a maximum, the hammer operates under optimum conditions.

In order to vary the pressure with which the hammer is forced against the work piece, it is possible to use a single movable weight upon a lever instead of the assembly of plates,

FIG. 4.



E, or it is possible to use springs, the tension of which is adjustable.

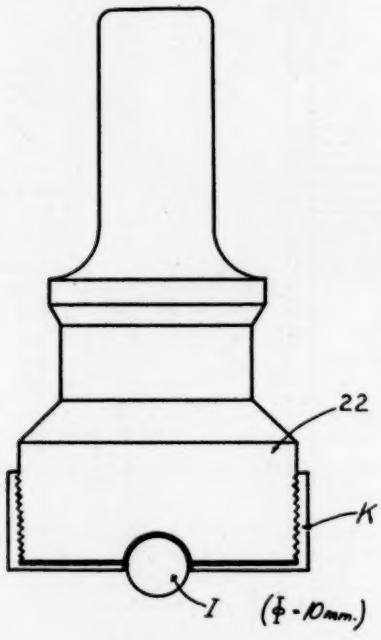
The riveter is held at its base by a bar, *F*, which has a hole in the middle, through which passes the air-barrel, 6, of the hammer. The air hammer is held in position between the holders at *F* and *C*.

Figure 5 shows the pivot set section in which provisions have been made for holding a ball of given diameter. A ball

of hardened steel, *I*, is attached interchangeably to the front of the rivet head, with a holder, *K*, screwed upon the front piece.[5] The standard size of these steel balls is ten and five millimeters in diameter.

In combination with the M. V. Schwarz drop tester, a ball of 6.35 millimeters diameter is used. Larger balls should be used for greater forces. The previously discussed equation (4) takes care of different ball diameters, *D*. For very con-

FIG. 5.



siderable forces, cylinders may be used instead of balls and the conversion tables calibrated accordingly.

Figure 3 shows part of the side view of the arrangement. The test bar, *H*, is moved under the rivet set, 22, at the front of which is inserted the steel ball, *I*, held by the clamp, *K*. The speed of this metal specimen, *H*, is such that each move-

[5] Balls made from the following alloys are recommended: (heat treated) 2.9 per cent. carbon, 13 per cent. vanadium, rest iron.—American Society for Steel Treating, 1927.

ment of the hammer makes a separate impression upon a fresh part of the bar.

For pushing the test bar ahead under the vibrating hammer, between the guides, *O* and *P*, an air feed mechanism, *R*, or an elastic spring pulley is used. This has the advantage of allowing the strip to hesitate at each impact of the piston during the time the ball is making the impression. If the piston recedes, the strip jumps ahead a small distance under the pressure of the elastic drive, while the strip stops for the short interval during which the impact takes place.

The speed of the driving mechanism is being regulated by the valve, *M*, so that the imprints do not overlap. On the same plate a second valve, M_2, is attached, by which the air for the riveter can be regulated. A main switch, *N*, permits the operation of both valves simultaneously. This facilitates the starting and stopping of the mechanism, after the pressure within the barrel and the speed of propagation have been adjusted.

The type of metal for making the testing bars depends upon the different forces of the riveters. For greater forces, harder, ferrous metals are used, while for smaller powers softer materials like brass and copper are more practical.

In operating this testing device for high speed hammers, the number of strokes per minute can be determined accurately from the number of indentations per time unit. It is possible to mark the time directly upon the bar by a special small hammer driven by an electromagnetic relay which in turn is operated by a pendulum indicating fraction of seconds. Thus the number of strokes per time unit can be read directly.

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Irradiated Yeast in the Ration.—R. F. LIGHT, L. T. WILSON, AND C. N. FREY (*Jour. of Nutrition*, 1934, VIII, 105–111) report that, when irradiated yeast is included in the ration of a dairy cow in the production of vitamin D milk, practically 100 per cent. of its vitamin D content is absorbed and appears in the blood. The concentration of this vitamin in the blood plasma governs its concentration in the milk; 2 to 3 per cent. of the ingested vitamin appears in the milk, the remainder either is destroyed in the body or is excreted; the disappearance from the blood is quite rapid.

J. S. H.

Soya Flour.—A. A. HORVATH (*Food Ind.*, 1935, VII, 15–16) advises a rapid inactivation of the native enzymes of soy beans by exposure to a sufficiently high temperature in the absence of oxygen. Deterioration of the product, by destruction of vitamins A and D, and by hydrolysis of the oil and oxidation of the products of this hydrolysis, are thereby prevented. The constituents which impart a "beany" taste, *e.g.* methyl normal monyl ketone, must also be removed. When soya flour is prepared in accordance with these specifications, it will keep for years in tin boxes or paraffined paper-lined bags. The flour contains, on the average, protein 40 per cent., oil 20 per cent., and lecithin 3 per cent., but no gluten, and practically no starch. Soya flour has found use as a diabetic food, and as a constituent of chocolate, ice cream, bread, macaroni, spaghetti, vermicelli, noodles, and pancake flour. In 1931, the United States produced almost 19,000,000 bushels of soybeans.

J. S. H.

Manganese Content of Sea Water.—THOMAS G. THOMPSON AND THOMAS L. WILSON (*Jour. Am. Chem. Soc.*, 1935, LVII, 233–236) report that the manganese content of sea water varies from 0.2×10^{-4} to 1.8×10^{-4} milligram atoms per kilo of water.

J. S. H.

Atomic Weight of Europium.—E. L. MEYERS AND B. S. HOPKINS (*Jour. Am. Chem. Soc.*, 1935, LVII, 241–243) have determined the ratio of europium chloride to silver, and thereby found the atomic weight of europium to be 152.30 with a mean deviation of $\pm$ 0.018.

J. S. H.

THE DYNAMICS OF MOLECULAR CRYSTAL LATTICES. II. SOLID NITROGEN.

BY

V. DEITZ.*

INTRODUCTION.

The case of solid nitrogen introduces several more complications in the dynamics of molecular crystal lattices. First, the lattice energy may be calculated between pairs of molecules or between pairs of the atoms of different molecules. Second, the crystal vibrations now include the rotational oscillations of the individual molecules.

London [1] has shown that the forces between a pair of molecules may be taken as the sum of the forces between the possible pairs of atoms of the different molecules. According to the X-ray analysis of $\alpha - N_2$ by Vegard,[2] the distance between the nitrogen atoms in the molecule is 1.065 Å. which is identical with the distance found for gaseous nitrogen. The distance between the center of one molecule and the center of the other along the edge of the unit cube is 5.64 Å. According to the crystal structure there are orientations of the four molecules which make up the unit cell. These are parallel to the four body diagonals of the cube. With these facts it is possible to calculate the distances between the various pairs of atoms. For the case of a simple monatomic face-centered lattice there are twelve nearest neighbors to any reference one, all twelve distances equal. In the case of N_2 there are forty-eight distances between the atoms of the reference molecule and the twelve nearest neighbors. Let A, B, C, D represent the four kinds of molecules according to the orientations of the molecules. We shall choose the molecule oriented A as the reference molecule; the atom above the

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[1] London, *Zeit. f. Phys. Chem.*, **B11**, 222 (1930).

[2] Vegard, *Zeit. f. Physik.*, **58**, 497 (1929).

XY plane through the center of the molecule is designated by a_0 and the atom below the XY plane by α_0. There are four closest neighbors of each of the remaining orientations; $b_1 \cdots b_4$, $c_1 \cdots c_4$, $d_1 \cdots d_4$ designate the atoms above an XY plane through the center of each molecule, and $\beta_1 \cdots \beta_4$, $\gamma_1 \cdots \gamma_4$ and $\delta_1 \cdots \delta_4$ designate the atoms below the XY plane. The sequence of the subscripts is clockwise around the reference molecule. The symmetry of the crystal is such that all molecules of *B* orientation are in a plane parallel to the 100 plane, all of *C* orientation are in a plane parallel to the 010 plane, and all of *D* orientation are in a plane parallel to the 001 plane. Table I*a* gives the numerical values calculated for these forty-eight distances. Furthermore, in the case of the monatomic lattice there are six next closest neighbors to the reference molecule. In the N_2 case there are twenty-four. These are of the same orientation as the reference molecule, and the distances are tabulated below. The third closest neighbors, twenty-four atoms in number, average a distance of 8.00 Å. from the reference atoms.

TABLE I*a*.

a_0b_1	3.64	$a_0\beta_1$	4.49	α_0b_1	3.58	$\alpha_0\beta_1$	4.53
b_2	3.64	β_2	3.58	b_2	4.49	β_2	4.53
b_3	4.53	β_3	3.58	b_3	4.49	β_3	3.64
b_4	4.53	β_4	4.49	b_4	3.58	β_4	3.64
a_0c_1	3.58	$a_0\gamma_1$	3.65	α_0c_1	4.53	$\alpha_0\gamma_1$	4.49
c_2	3.58	γ_2	4.53	c_2	3.65	γ_2	4.49
c_3	4.49	γ_3	4.53	c_3	3.65	γ_3	3.58
c_4	4.49	γ_4	3.65	c_4	4.53	γ_4	3.58
a_0d_1	3.58	$a_0\delta_1$	4.53	α_0d_1	3.64	$\alpha_0\delta_1$	4.49
d_2	3.58	δ_2	3.64	d_2	4.53	δ_2	4.49
d_3	4.49	δ_3	3.64	d_3	4.53	δ_3	3.58
d_4	4.49	δ_4	4.53	d_4	3.64	δ_4	3.58

TABLE I*b*.

a_0a_1	5.66	$a_0\alpha_1$	6.30	α_0a_1	4.96	$\alpha_0\alpha_1$	5.66
a_2	5.66	α_2	6.30	a_2	4.96	α_2	5.66
a_3	5.66	α_3	6.30	a_3	4.96	α_3	5.66
a_4	5.66	α_4	6.30	a_4	4.96	α_4	5.66
a_5	5.66	α_5	6.30	a_5	4.96	α_5	5.66
a_6	5.66	α_6	6.30	a_6	4.96	α_6	5.66

The lattice energy per atom of the molecule is given by equation (1):

$$\Phi_0 = \frac{1}{2}\left[- S_l \sum_\kappa \frac{c_{ij}}{r_\kappa^6} - S_l \sum_\kappa \frac{d_{ij}}{r_\kappa^8} + S_l \sum_\kappa b e^{-r_\kappa/\rho} \right] + \frac{E_0}{2}$$

$$= - \frac{\Delta H_{\text{sub.}}}{2}, \quad (1)$$

wherein S_l is a summation over the lattice and $\sum_\kappa$ is to take care of the number of different atomic spacings. The value of c_{ij} is taken from Table I of the previous article and yields a value for $d_{ij} = 15.77 \times 10^{-76}$ erg-cm.[8] The polarizability of the nitrogen atom in the molecule may be taken to be one-half that of the molecule. From equation (1) and its first derivative we obtain the following two relations which determine the two constants ρ and b of the repulsion potential.

$$1/2[(-2.995 - 0.122)10^{-13} + bS_l \sum_\kappa e^{-r/\rho}]$$

$$+ \frac{0.105 \times 10^{-13}}{2} = - \frac{1.128}{2} \times 10^{-13} \text{ erg,}$$

per atom of molecule

$$\left[(+ 4.672 + 0.196)10^{-5} - \frac{b}{\rho} S_l \sum_\kappa e^{-r/\rho} \right] = 0.$$

The results are: $\rho = 0.387 \times 10^{-8}$ and $b = 0.795 \times 10^{-10}$.

The repulsion between two nitrogen atoms of different N_2 molecules in the crystal is thus seen to be less steep than that between two neon atoms, which, in turn, is less than that between two argon atoms. This is in keeping with the atomic radii of the atoms.

	N.	Ne.	A.
$\rho \times 10_8$	.387	.276	.134
$r_e \times 10_8$	.53	.63	.87

The radius for N is taken from Vegard [2] and that for Ne and A from the I. C. T. tables.

Before proceeding with the calculation of the frequencies and the heat capacity it may be of interest to see why the lattice potential of solid nitrogen is a minimum for the par-

[2] Vegard, *Zeit. f. Physik.*, **58**, 497 (1929).

ticular orientations of the molecules reported above. Let θ and φ be the two space polar coordinates fixing the orientation of a molecule. It is easy to obtain the two equations for the two unknowns. However, a laborious algebraic manipulation would be required to obtain a solution. Instead, one may assume certain values for θ and ϕ, and calculate the corresponding lattice potential. When all the molecules are lined up so as to be parallel to each other, the lattice potential turns out to be positive, indicating, of course, instability. When the molecules at the corners of the unit cell are along, say, the X axis, and those in the middle of the faces are along the Z axis, the potential is also positive. Finally, with the molecules in the 100 plane parallel to the X axis, those in the 010 plane parallel to the Y axis, and those in the 001 plane parallel to the Z axis, the potential is again positive.

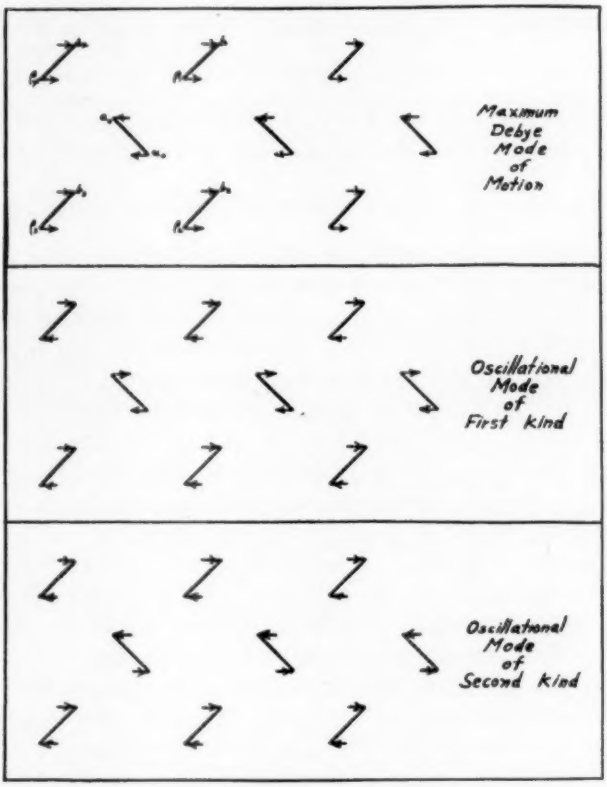
CRYSTAL LATTICE VIBRATIONS.

The case of nitrogen presents several interesting possibilities in connection with the crystal vibrations. As in the neon calculation, there is the mode of vibration in which the molecule as a unit is displaced. The maximum vibration for such a motion may be called the Debye motion, and is sketched diagrammatically at the top of Fig. 1. It is possible further to postulate two motions which will result in all the molecules oscillating, instead of just those which happen to be at the nodal point of a Debye vibration. These are sketched in the middle and bottom parts of Fig. 1. The amplitudes of these oscillations increase as the temperature increases, and the vibration may go progressively through non-uniform rotation into a uniform rotation of the molecules.

The mode of vibration called "oscillations of the first kind" is one where the top atoms of all the molecules in Fig. 1 are displaced to the right, while those on the bottom move to the left. The distances which suffer displacement are the groups $a_0\beta_i$, $a_0\gamma_i$, $a_0\delta_i$ and the groups $\alpha_0 b_i$, $\alpha_0 c_i$, $\alpha_0 d_i$, where i takes on the values 1, 2, 3 and 4. The second possibility, called "oscillations of the second kind," arises from the displacement in one direction of the top atoms of the molecules in one plane and the bottom atoms of the molecules in the plane just above; the reverse displacement holding for the atoms in

the next two corresponding planes, as shown in Fig. 1. In this case, the distances to be considered are the groups a_0b_i, a_0c_i, a_0d_i and the groups $\alpha_0\beta_i$, $\alpha_0\gamma_i$, $\alpha_0\delta_i$.

FIG. 1.



To calculate the maximum Debye frequency we use the following equation:

$$\theta_D = \frac{h\nu}{k} = \frac{h}{\pi k}\sqrt{\frac{K \times 6.06 \times 10^{23}}{14}}, \qquad (2)$$

where ν is the frequency and K the force constant, calculated as in the previous article; the only variation being a slight change to take account of the particular mode of vibration. The results are assembled in Table II.

TABLE II.

	$\Phi''_{\text{Attrac.}}$	$\frac{\Phi'_{\text{Attrac.}}}{r_0}$	$\Phi''_{\text{Repulsion.}}$	$\frac{\Phi'_{\text{Repul.}}}{r_0}$	K.	$\theta_{\text{(Calc.)}}$	$\theta_{\text{(Exp.)}}$
Debye...	− 5610	+ 800	+ 8310	− 875	656	81	92
I.....	− 4398	+ 619	+ 6055	− 637	410	64	57
II.....	− 4583	+ 645	+ 6395	− 674	446	67	—
I + II...	—	—	—	—	856	93	99

The only check we have for the maximum Debye frequency comes from the Lindeman melting point formula: $\theta = 147.10\sqrt{\frac{Tm}{MV^{2/3}}}$ where Tm is the melting point, 63.1° K.; M is the molecular weight, 28; and V is the molecular volume, 13.6 cc./mol. This value turns out to be 92. The remaining frequencies are of interest in examining the work of Vegard [3] in connection with the spectrum obtained by him from solid nitrogen at liquid hydrogen temperatures. Vegard can account for the spectrum that he obtains by first a change in the electronic state; second by a change in the vibrational states of the atoms in the molecule of nitrogen; third by an additional change corresponding to the frequencies of 40 cm.$^{-1}$ and 69 cm.$^{-1}$, which he interprets as oscillational jumps for the molecule in the lattice. These frequencies, which correspond to values of θ of 57 and 99, can hardly be accounted for by the usual Debye frequencies, which, if they could be observed, would yield a continuous band of frequencies. The above calculated results indicate the validity of Vegard's interpretation. The frequency of 40 cm.$^{-1}$ is to be associated with transitions between the energy levels of either kind of the oscillations that we have postulated and, the frequency of 69 cm.$^{-1}$ is to be associated with a combination of the two kinds of oscillation.

As a final check the heat capacity may be calculated and compared with the experimental results.

$$Cp(\text{total}) = C_{\text{Debye}} + C_{\text{Oscillation}} + C_{\text{Vib.}} + (\text{work term})$$

θ_D was taken equal to 81°, the oscillational frequency of 57° was given two degrees of freedom, the contribution of the

[3] Vegard, *Nature*, **125**, 14 (1930).

internal vibration of the molecules, $C_{vib.}$, is negligible. The work term was calculated from the expression of Nernst: $Cp - Cv = (.0214)(Cp)^2 \frac{T}{Tm}$, where Cp is the experimental value of the heat capacity, Tm is the melting point. The results are given in Table III up to 30° K., a transition into

TABLE III.

°K.	C_D.	$C_{Oscil.}$	$C_p - C_v$	$C_{pTotal.}$	$C_{p(Exp.)}$.
10	.82	.44	.01	1.27	1.3
15	1.93	1.34	.05	3.32	2.97
20	2.95	2.10	.15	5.20	4.62
25	3.71	2.62	.34	6.67	6.30
30	4.25	2.96	.67	7.88	8.09

the β-modification of solid nitrogen occurring not far above the temperature.

One must realize, of course, that it is only a first approximation to take the heat capacity as the sum of a Debye function, corresponding to the translational oscillations, and twice an Einstein function for the oscillation of the molecules about equilibrium orientations. Such a model is too greatly simplified, as pointed out by Fowler and Sterne.[4]

The author takes this opportunity to thank Professor D. H. Andrews for advice and suggestions.

URBANA, ILLINOIS,
September 21, 1934.

[4] Fowler and Sterne, *Rev. of Mod. Physics*, **4**, 670 (1932).

Food Preservation in Relation to Public Health.—In the Wiley Memorial Lecture, W. D. BIGELOW (*Jour. Asso. Off. Agric. Chem.*, 1935, XVIII, 21–30) discusses the problem of food preservation in relation to public health. Milled cereals, sugar, and refined vegetable oils form considerably more than one-half of the daily caloric intake of man; yet these foods supply scarcely any of the mineral elements and vitamins, and leave much to be desired with respect to their protein constituents. These deficiencies are supplied and health is maintained by adequate consumption of dairy products, succulent vegetables and fruits. In order to make these perishable products generally available, some form of preservation is necessary, *e.g.*, drying and dehydration, curing and smoking, fermentation and pickling, canning, refrigeration above or below freezing, and chemical preservatives. In sun-drying and in dehydration by means of an air current of controlled temperature and humidity, the antiscorbutic vitamin, water-soluble C, is inadequately preserved; cured and smoked products are practically devoid of this vitamin. Fermentation and pickling apparently have no effect on vitamins A and B, and fermentation in the absence of oxygen does not injure vitamin C. Fruits and vegetables are usually canned with added sirup or brine, which must be eaten also in order to obtain the full nutritive value.

The process of canning does not affect vitamins A, D, G, and E, may produce a material loss of vitamin B (F) in leafy vegetables like spinach, but practically no loss of this vitamin in peas and other vegetables. The destruction of vitamin C by canning is extremely slight in the fruits, and may be appreciable in vegetables, but practically always is less than the destruction produced by cooking similar market products in an open kettle by the usual kitchen methods. The heat of sterilization in canning increases the availaability of the food calcium for use by the animal body. While the vitamin C content of raw fruits and vegetables may deteriorate during transportation and holding under refrigeration above freezing, yet those species which normally are rich in that vitamin still retain an adequate quantity of it. Frozen vegetables and fruits are still in the experimental stage; they must be kept frozen until consumed; and vegetables must be heated sufficiently to inactivate their native enzymes prior to freezing. As to chemical preservatives, they should be restricted to the utmost practicable extent, since several foods from different manufacturers but preserved with the same chemical compound may be eaten at the same time, and since preservatives may exert a cumulative effect after being ingested regularly during a long period of time.

J. S. H.

PERIODS OF VIBRATION OF BUILDINGS AN INDEX TO THEIR END CONDITIONS.

BY

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In the dynamical design of aseismic structures, earthquake forces are assumed to be dynamic, and not static in character. Hence, in addition to the data investigated by the statical method, other factors are taken into account. For example, the effects of the dominant periods of the site, discontinuity between the site and foundation, synchronism between building and earthquake periods, and the end conditions of the building are considered. The last two factors are of profound importance in determining the magnitudes and locations of the maximum seismic moments and shears.[1]

To illustrate: The late John R. Freeman states: [2]

"Plainly there is a somewhat paradoxical condition, difficult of precise analysis, in the undoubted facts that:

"1. The earthquake motion will be far more severe on soft, mobile, unstable ground, like wet alluvial deposits or made-land, than upon rigid ground or ledge.

"2. That for equal earthquake motion a carefully designed rigid building on soft yielding ground will suffer much less damage than one of equal strength located on rigid ground."

Again, quoting T. Naito: [3]

"The majority of those who have observed the different buildings in Marunouchi have drawn the conclusion that the point three-tenths of the total height is the most vulnerable spot from the standpoint of damage by earthquake. However, a more accurate survey of the damage will indicate that the above conclusion is not always true."

Now the statical method of aseismic design assumes, in general, that buildings are vertical cantilevers, subjected dur-

ing quakes, to a static horizontal force equal to a percentage of the dead and live loads above the section under consideration, the percentage chosen depending on the distance from active faults, and on the type of soil encountered. From the statical point of view, since maximum shears and moments in vertical cantilevers are at the bottom, the maximum earthquake damage should center at that point. But, as the above authorities have noted, such is not the case, so that these phenomena remain paradoxes from the point of view of the statical method.

However, the author has shown elsewhere [4] that if the relation between the building and earthquake periods, and the end conditions are taken into account, that a building on soft ground should suffer less damage than one of equal strength on rigid ground; also that the maximum moment may occur at any point between the bottom of the building and 0.43 its height, and that the maximum shear may be between the bottom and 0.75 its height. Hence, the maximum seismic damage may center at any plane of weakness between the bottom and 0.75 the height of a building. Obviously, these statical paradoxes are only phenomena which are expected theoretically, by the dynamical method.

In a previous paper,[5] it was shown that, other factors remaining constant, increased periods of vibration in a building indicate decreased elastic resistance, i.e., that the periods of vibration may be used to check changes in the structural integrity. In this paper the author will show that the ratio of the periods in a building may be used to determine its end condition, or, more simply, the degree of fixity between the building and the native soil, if the building is free standing; or between the building and the contiguous media, if the building is restrained by adjoining structures as well as gripped by the soil.

As stated above, these data are essential for the purposes of dynamical aseismic design and analysis. For example, with the end conditions and physical characteristics of a building known, it is possible to compute its free periods of vibration, and its seismic deflections, moments, and shears. Again, having assumed end conditions for a proposed building, a valuable check on the design consists in determining the actual

end conditions. Again, in the investigation of an existing building, with the end conditions known, it is possible to evaluate its earthquake-resistant strength. Finally, it is important to know whether the end conditions of a building have changed during an earthquake, before it is possible to interpret the significance of the new periods.

END CONDITIONS OF BUILDINGS.

If a building is deflected, and then released, it is thrown into *free vibration*. Theoretically, a building can vibrate freely in an infinite number of ways or *modes*. Certain modes, however, are known as the *normal* modes. It can be shown that any free vibration is some combination of the normal modes. Of these, the mode of largest period is the *fundamental;* those of smaller periods the *harmonics*. Next to the fundamental, the *first harmonic* has the largest period of vibration.

A building vibration may be split up into components along the three axes X, Y, and Z. Along each of these, the different modes may occur. The ratio of the fundamental to the first harmonic period along any axis, indicates the *end condition* of the building about that axis.

For tall buildings, i.e., buildings whose ratio of height "L" to depth in the plane of vibration "d" is greater than 5, the equation for the free periods about any axis is [6]

$$T = c\sqrt{\frac{wL^4}{EIg}},$$

where T = free period, sec.,
c = constant expressing end conditions during vibration,
L = height of building, in.,
E = Young's modulus, lbs. per in.^{2},
I = moment of inertia, in.^{4},
g = acceleration due to gravity, in. per sec.^{2},

For short buildings, i.e., where L/d is less than 5, the preceding equation is modified by [7]

$$T_t = \sqrt{T^2\left[1 + \frac{d^2}{4c_1L^2}\right]},$$

where T_t = true period of a short building, in.,
c_1 = constant of static deflection,
d = depth of building in the plane of vibration, in.

In the first equation, it may be noted that "c" is most influential in determining period values; hence, it is essential that "c" represent actual end conditions, if correct periods are to be obtained.

Four cases of free vibration, each with different end conditions, will now be considered.

1. *Fixed-Free.*—As used here, the term *fixed* means fixed for translation and rotation, or, fixed for shear and moment; and, *free* means free for translation and rotation, or, free for shear and moment. The first term refers to the end condition at the bottom of the building, and the last term to the end condition at the top. Hence, *fixed-free* means fixed at the bottom and free at the top. For this case [8]

$$T = 1.79\sqrt{\frac{wL^4}{EIg}}, \qquad T_1 = 0.29\sqrt{\frac{wL^4}{EIg}},$$

where T = fundamental period, and T_1 = first harmonic period.

2. *Sliding-Free.*—As used here, the term *sliding* means free for translation but fixed for rotation, or, free for shear but fixed for moment. For this case [9]

$$T = 1.12\sqrt{\frac{wL^4}{EIg}}, \qquad T_1 = 0.21\sqrt{\frac{wL^4}{EIg}}.$$

3. *Hinged-Free.*—As used here, the term *hinged* means free for rotation but fixed for translation, or, free for moment and fixed for shear. For this case [10]

$$T = 0.41\sqrt{\frac{wL^4}{EIg}}, \qquad T_1 = 0.13\sqrt{\frac{wL^4}{EIg}}.$$

4. *Free-Free.*—For this case [11]

$$T = 0.28\sqrt{\frac{wL^4}{EIg}}, \qquad T_1 = 0.10\sqrt{\frac{wL^4}{EIg}}.$$

Tabulating the numerical coefficients in the fundamental

and first harmonic period equations, and obtaining the ratios of the fundamentals to the first harmonics, the following schedule results:

End Conditions.	Coefficient of T.	Coefficient of T_1.	T/T_1.
Fixed-Free	1.79	0.29	6.2
Sliding-Free	1.12	0.21	5.3
Hinged-Free	0.41	0.13	3.2
Free-Free	0.28	0.10	2.8

With the aid of this table, it is possible, knowing the fundamental and first harmonic periods about any axis, to determine the end conditions about that axis. This may be done by calculating the T/T_1 ratio, and then referring to the T/T_1 column in the table. For example, say that the fundamental period about an axis is $T = 0.81$ second, and the first harmonic about the same axis is $T_1 = 0.13$ second. Then, $T/T_1 = 6.2$. Referring to the table, it is obvious that the end conditions are fixed-free about that axis.

APPLICATION TO BUILDINGS.

Before applying these data to buildings, certain arbitrary assumptions will be made. Thus, the end condition at the top of a building will be considered as *free*.

At the bottom of a building, if the foundation is fixed into bedrock, or into dry, compact, alluvial or diluvial deposits, the end condition will be assumed as *fixed*. Where a layer of gravel separates the foundation from the native soil, and provision is made to permit the foundation to slide, the end condition will be considered as *sliding*.

If the foundation is fixed into wet, compressible deposits of such nature that rotation in a vertical plane can occur, the end condition will be assumed as *hinged*. Where a layer of gravel separates the foundation from the wet soil, and the building is able to slide, the end condition will be assumed as approximately *free*.

In practice, the end conditions ordinarily have no definite limits, but rather merge into one another. For any particular case, the determination of the end conditions may be further complicated by reason of the lateral restraint imposed by

contiguous structures. Obviously, therefore, after all the factors involved are evaluated, it becomes a matter of engineering judgment to decide how closely any of the above arbitrary standards are approached, and what value of "c" shall be assigned.

These remarks apply, of course, only to the design of proposed buildings. For the purposes of analysis of existing structures, whose periods have been measured, and T/T_1 ratios calculated, the problem is simpler, and consists merely of interpolating in the table for a value of "c."

METEOROLOGICAL EFFECT ON END CONDITIONS.

Since the degree of compressibility of soil is a function of its moisture content, and the moisture content is influenced by meteorological variations, it is to be expected that compressible soils will be more or less compressible according to the prevalence of flood or drought. Consequently, since the degree of soil compressibility influences the end conditions, and inasmuch as the end conditions affect the value of the periods of vibration, it follows that the periods of vibration should vary with the moisture content, in compressible soil. Experimental evidence confirms this conclusion, it having been observed that the periods of structures on compressible soil change after a heavy rainfall.

Therefore, in deciding on a value of "c" to use, the effects of flood and drought should be considered. It may be found that two limiting values of "c" may be required, for safety.

VIBROGRAPHS.

What type of instrument should be used to measure periods of vibration? An ideal instrument should give records not only of periods and amplitudes, but also of wave forms and phase relations along all three axes. In addition, considerable sensitivity is required, the amplitudes of vibration of buildings due to wind or traffic pulses being of the order of 0.001 inch. At the same time, instruments must not be too delicate, or much time will be spent in making adjustments. Finally, they should be so designed and constructed, that they can be transported and set up readily.

In the past, the usual instruments recorded amplitude and

period along one axis only. Others showed wave form and amplitude along one axis. These types ordinarily employed pen or stylus recorders, and it is doubtful whether these are accurate over all ranges.

Recently, however, instruments have been designed and built which seem satisfactory. For example, H. E. McComb, of the United States Coast and Geodetic Survey and Dr. F. Wenner of the National Bureau of Standards, have developed an efficient vibrograph for recording large-period, low-acceleration, small-amplitude vibrations. Again, for the recording of small-period, high-acceleration, small-amplitude vibrations, the Shrader Tri-Dimensional Vibrograph [12] is quite convenient.

THEORY vs. PRACTICE.

Engineers and architects will, of course, be interested to learn of applications of the theory previously presented. The following illustrative data, although limited in number, are sufficient, it is believed, to establish the point that theory and practice are not too far apart.

1. The site of the Washington Monument was chosen originally because it was believed to be a bed of closely compacted sand and gravel. After the construction was completed, however, it was found that the monument was settling at the average rate of one-fortieth of an inch annually. Obviously, there was some soft material under the sand and gravel deposit.

Borings taken in 1931 disclosed that layers of sand, gravel, and clay, or mixtures thereof, were to be found between the foundation of the monument and bedrock. The engineers' report states [13] that "the deposit of clay overlying the rock in the vicinity of the Washington Monument is in such soft and moist condition as to be liable to flow under any considerable shifting of its superimposed load." It may therefore be assumed that the monument is on wet compressible deposits of such nature that rotation in a vertical plane can occur. Also, the foundation rests on sand and gravel, so that it may be able to slide slightly, although no provision was made, of course, when the monument was built to enable it to slide freely.

Evaluating these data, it is reasonable to assume that the end conditions of the Washington Monument will lie between

hinged-free and free-free, say halfway between the two cases. From the table, therefore, the theoretical value of T/T_1 is 3.0.

The free periods of transverse vibration of the monument were measured by F. Neumann of the United States Coast and Geodetic Survey. They were found to be:[14]

Fundamental Period, $T = 1.81$ seconds.
First Harmonic Period, $T_1 = 0.60$ second.
Hence, the actual value of the ratio T/T_1 is also 3.0.

In this case, theory and practice are in excellent agreement.

It is to be noted that the dry layers of sand and gravel do not prevent the compressible behavior of the underlying wet material.

2. The United States Coast and Geodetic Survey under the able and energetic leadership of Director R. S. Patton, and Captain N. H. Heck, and under the field direction of F. P. Ulrich, is engaged in conducting measurements, on a large scale, of building vibration periods in California. At the time that periods are measured, information is also obtained concerning the nature of the soil constituting the building site, the intention being to compare period ratios, i.e., T/T_1 values, with the soil conditions. Inspection by the author of some of the preliminary results discloses a remarkable and definite relationship between measured period ratios and end conditions. It is highly probable that a scientific criterion for judging end conditions of buildings by means of the soil characteristics of the site will eventuate from these data.

3. To illustrate the method of choosing the end conditions of buildings, and of judging the nature of the soil on which they rest, the author indulges in the following guesses concerning two San Francisco buildings, of rectangular plan. The periods of vibration of these buildings were measured by Messers Byerly, Hester, and Marshall.[15]

The Alexander Building.—Horizontal dimensions, 60 by 69 feet. Fifteen stories, 205 feet high. No adjoining buildings except on one side where a building rises to the fourth floor. The measured periods were:

East-west, $T = 1.32$ sec., $T_1 = 0.41$ sec., $T/T_1 = 3.2$,
North-south, $T = 1.23$ sec., $T_1 = 0.39$ sec., $T/T_1 = 3.2$.

Referring to the table, it is noted that the end conditions are hinged-free. The author concludes that the building rests on compressible soil, even if the building foundations are in immediate contact with relatively incompressible materials.

The Insurance Center Building.—Horizontal dimensions, 84 by 206 feet. Sixteen stories, 206 feet high. Restrained on two sides by a building which extends to the fifth floor, on the third side by a structure which rises to the third floor. The measured periods were:

North-south $T = 1.41$ sec., $T_1 = 0.20$ sec., $T/T_1 = 7.0$,
East-west, $T = 1.07$ sec., T_1, missing.

Referring to the table, it is noted that T/T_1 exceeds the value for the fixed-free case, or 6.2. This might be interpreted to mean that the contiguous structures increase the degree of fixity over that which it would be if the building were free-standing. For the purposes of a seismic investigation, the author would assume the fixed-free case. The author concludes that the Insurance Center Building rests on incompressible soil.

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Benzoyl Auramine G: a New Indicator.—JOHN T. SCANLAN AND J. DAVID REID (*Ind. and Eng. Chem.*, Analytical Edition, 1935, VII, 125–126) recommend benzoyl auramine G as an indicator in the volumetric determination of nitrogen by the Kjeldahl method. This indicator changes from an intense violet at pH 5.0 to a pale yellow at pH 5.6.

J. S. H.

Selenium Problem.—As early as 1856, T. C. MADISON, an army surgeon, described a fatal disease of cavalry horses at Fort Randall, South Dakota, and correctly attributed it to their pasturage. HENRY G. KNIGHT (*Jour. Asso. Off. Agric. Chem.*, 1935, XVIII, 103–108) summarizes recent studies of this so-called alkali disease, which is now known to be due to the presence of the element selenium in the forage plants. While selenium has a wide distribution as a soil constituent, it seldom occurs in amount sufficient to produce definitely toxic vegetation. However, in certain localities, the selenium content of the forage plants is so great that it may produce either acute or chronic poisoning with a fatal termination, or else interfere with normal growth, development, and function. Fortunately, the most toxic vegetation occurs, as a rule, on non-arable grazing land. Definitely toxic areas of this land have been found in six different states. Apparently selenium-containing soils are limited to arid or semi-arid districts, and to clays developed from shales in which seleniferous pyrite was present. Selenium occurs in these soils in both organic and inorganic form, and in plant and animal tissues in at least two forms. Selenium concentrates in the protein portion of seeds, and in the glutens of wheat, in a form practically insoluble in water. In growing plants, most of the selenium compounds are soluble in hot water. Grain from foreign sources has been found to contain selenium. Outside the affected areas, the danger is minimized, since selenium-containing food products generally form only a small part of the daily diet of any individual.

J. S. H.

STRESSES IN RADIALLY LOADED DISCS.

BY

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The problem of exactly determining the magnitudes of stresses created in discs, or comparatively short rollers, by the action of concentrated radial loads is often encountered in practical engineering work. Designers, either because of their unfamiliarity with the theory of elasticity or because of their impatience with the lengthy and complicated computations which usually result from the application of elastic theory, will take the path of least resistance and resort to "intuitive design" when confronted with such a problem. The stress conditions induced in a disc by two diametrically opposed concentrated loads are fully and accurately treated in conveniently accessible literature; but, unfortunately, no literature on the absolutely general solution—for a disc subjected to *any* number of radial loads—seems to be available. The so-called "general" solutions which have appeared from time to time are invariably restricted in their application. Some require that the loads be equally spaced, others that the loads have equal magnitudes, etc.

The purpose of this paper is to present an exact, yet simple, analytical method for calculating the magnitudes of the stresses which are produced in a disc or short roller by the action of any number of concentrated radial loads applied to its periphery. The method of solution depends upon the superposition of similar individual analyses which are made for each load as though it were acting independently of all others. It differs from previous methods in that the final expressions obtained for the magnitudes of the Cartesian stress components are compact and easy to evaluate. This difference is due primarily to the fact that the expressions are derived without considering the static equilibrium of the ap-

plied loads until the question of boundary conditions arises, i.e., until *after* the superposition summation has been performed.

Expressions for the normal and shearing stresses created in a disc for the hypothetical case of one load acting alone are first derived. These expressions are then applied successively to each of the "one load" cases, of which there are obviously as many as there are applied loads. The component stresses at any point, resulting from the simultaneous action of all loads, are simply the summations of the components determined independently for each load. It is to be understood that the expressions for the component stresses must be derived in such a way that the principal boundary condition is not violated (i.e., no stresses may exist at any points on the disc's periphery other than those coincident with the points of load application, in which case the stress is infinite).

Regardless of whether the disc is subjected to any number of compressive radial loads, tensile radial loads, or to any conceivable combination of the two, the following method of analysis is completely applicable. The concentrated loads may have any spacing or any magnitude so long as they are in static equilibrium when considered as a complete force system. The only stipulations connected with the proposed method of analysis are: (1) that the applied loads shall hold the disc in static equilibrium; (2) that the disc must be of negligible weight as compared to the magnitudes of the applied loads.

DERIVATION OF THE COMPONENT STRESS EQUATIONS.

The continuity equation for generalized plane stress, in which the body and inertia forces are assumed to be zero, is

$$\frac{\partial^4 \phi}{\partial x^4} + 2\frac{\partial^4 \phi}{\partial x^2 \partial y^2} + \frac{\partial^4 \phi}{\partial y^4} = 0, \qquad (1)$$

where $\phi(xy)$ is an Airy's stress function whose form depends upon the boundary conditions of the particular coplanar stress problem being studied.

The stress components[1] are directly derivable from the

[1] Notation for stress components is the same as that used in "A Treatise on the Mathematical Theory of Elasticity," A. E. H. Love.

Airy's stress function. In polar coordinates they are

$$\widehat{rr} = \frac{1}{r^2}\left(\frac{\partial^2\phi}{\partial\theta^2}\right) + \frac{1}{r}\left(\frac{\partial\phi}{\partial r}\right),$$

$$\widehat{\theta\theta} = \left(\frac{\partial^2\phi}{\partial r^2}\right), \qquad (2)$$

$$\widehat{r\theta} = \frac{1}{r^2}\left(\frac{\partial\phi}{\partial\theta}\right) - \frac{1}{r}\left(\frac{\partial^2\phi}{\partial r\partial\theta}\right).$$

In order to proceed with our specific problem of determining the stresses produced in discs by radial loads, it is obviously necessary to find an expression for ϕ which will meet the requirements of Equation 1, as well as the further requirement that any point on the disc's periphery, other than a point of load application, must be entirely free of stress. This can be done without recourse to a profound mathematical treatment of the fourth order partial differential equation which we have called Equation 1. A bit of deductive manipulation with the well known Airy's function for a single force applied perpendicularly to the edge of a semi-infinite plate,[2] as shown in Fig. 1, will not only serve our purpose just as well as mathematical rigour, but will lead us to the satisfactory expression for ϕ with a minimum of effort.

The Airy's function for the case represented by Fig. 1 is

$$\phi = -\frac{F}{\pi h} r\theta \sin\theta, \qquad (3)$$

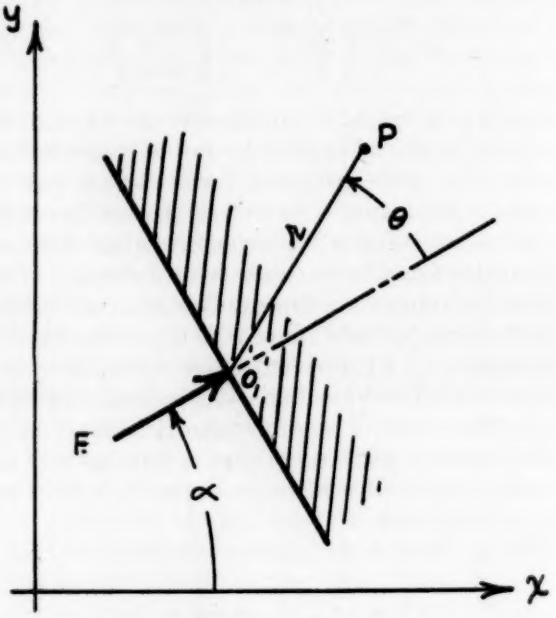
where ϕ = Airy's stress function,
F = the concentrated load, applied uniformly along the thickness of the plate, at point O_1 (lbs.). [$+F$ = compressive load; $-F$ = tensile load],
h = the thickness of the plate (inches),
α = the angle between the direction of F and the positive x axis,
r, θ = the polar coördinates of any point "P" referred to O_1, as the origin or pole.

Let us now consider this same function (Equation 3) as being

[2] Michell, J. H., "Elementary Distributions of Plane Stress." *Proc. of London Math. Soc.*, **32**: 35 (1900).

applied to the hypothetical case of a single radial force acting on the periphery of a disc, as shown in Fig. 2. The disc, although actually not in static equilibrium under such circumstances, is assumed to be fixed in space during the remainder of our analysis.

FIG. 1.



For the above figure, we shall let

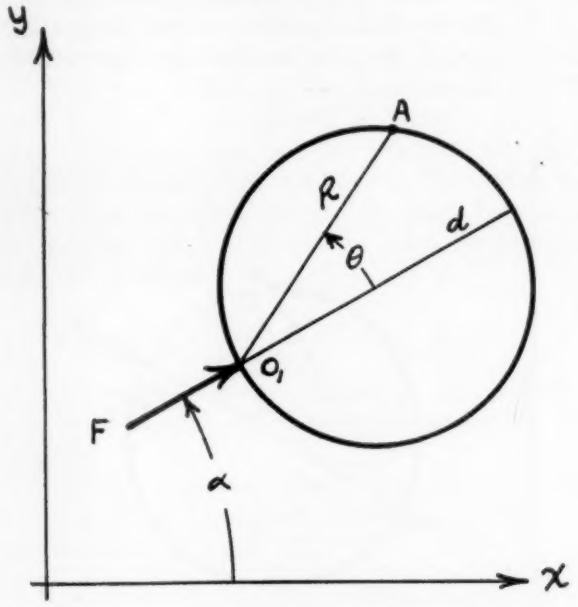
d = the disc diameter (inches),
h = the disc thickness (inches),
R = the particular value of the radial coördinate r to points, such as "A," on the disc's periphery (inches).

Then, from Equations 2 and 3, the stresses at any point on the disc's periphery are

$$\begin{aligned} \widehat{rr}_A &= -\frac{2F\cos\theta}{\pi hR} = -\frac{2F}{\pi hd}, \\ \widehat{\theta\theta}_A &= 0, \\ \widehat{r\theta}_A &= 0. \end{aligned} \tag{4}$$

The above set of equations indicates that the radial stress is a compression which is constant for all points on the periphery, other than the singular point of load application. This in turn means that the boundary condition of our problem is violated, since it is manifestly impossible for a component of stress to exist along a direction normal to the free edges of any elastic medium.

FIG. 2.

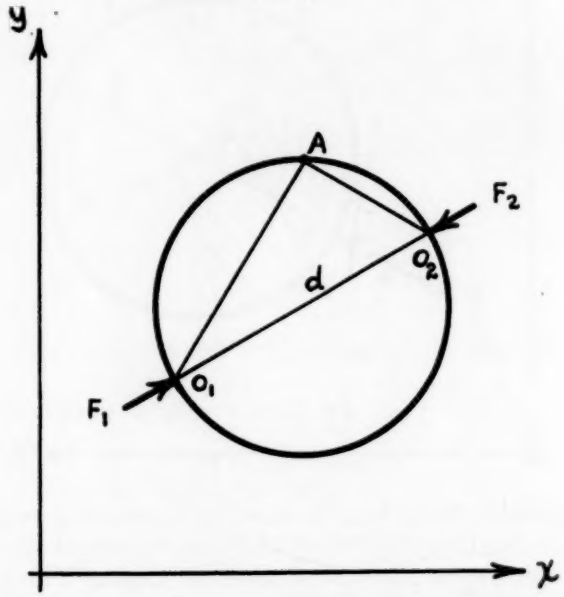


A possible remedy for this boundary violation suggests itself from a brief consideration of a disc in actual equilibrium under the action of the fewest possible loads. The case of a disc compressed along a diameter, as shown in Fig. 3, meets our requirements. The loads F_1 and F_2 obviously must be equal, and to indicate this fact we shall simply say $F_1 = F_2 = F$, where F is some constant magnitude.

The stress induced at "A" by F_1 is, from Equation 4, a compressive stress $-2F/\pi hd$ along the line $\overline{O_1A}$. Since $F_2 = F_1$ it follows that F_2 induces a compressive stress at "A" of equal magnitude but along the line $\overline{O_2A}$, which, by the

geometry of Fig. 3, is perpendicular to $\overline{O_1A}$. Superposing the effects of F_1 and F_2 leads to the conclusion that point "A" is in a state of hydrostatic compression. This violation of the boundary condition seemingly is no more desirable than the one originally arising from the interpretation of Equations 4. Still, if a uniform hydrostatic tension, equal in magnitude to the hydrostatic compression resulting from the combined effects of F_1 and F_2, could somehow be superposed upon the disc, "A" would then be completely unstressed and the boundary condition of the problem would be satisfied. Let us see if this could be done by modifying Airy's stress function as defined by Equation 3.

FIG. 3.



Inspecting Equations 2, we find that a function of the form

$$\phi = \text{constant} \times r^2 \tag{5}$$

will lead to equal and constant magnitudes for the stress components $\widehat{rr}$ and $\widehat{\theta\theta}$, while $\widehat{r\theta}$ will be zero. Therefore, by selecting a suitable constant for Equation 5, we can obtain a function ϕ which, when added to the function defined by Equation 3, will superpose a hydrostatic tension upon all

points in the disc. Inasmuch as we are considering the case of two loads, we must be careful to evaluate the constant in Equation 5 so that each load will contribute one-half of the total hydrostatic tension. The combination of Equations 3 and 5, with the constant evaluated, yields for our new Airy's stress function

$$\phi = -\frac{F}{\pi h} r\theta \sin\theta + \frac{F}{2\pi hd} r^2. \tag{6}$$

It should be noted that Equation 6 is intended to be used for determining the effect of a single load acting independently of any other loads. From this it follows that Equation 6 will be applied as many times as there are loads, and that the variables F, r, and θ must always be referred to the point of application of the particular load being studied. We can express Equation 6 mathematically in a form which will imply its method of application. If "n" loads act upon the disc, then we can say that the stress function for any particular one of the "n" loads is

$$\phi_n = -\frac{F_n}{\pi h} r_n\theta_n \sin\theta_n + \frac{F_n}{2\pi hd} r_n^2, \tag{7}$$

where it is understood that the subscript "n" is used to identify the expression with the particular one of the "n" loads being studied.

Let us now try Equation 7 on the case depicted by Fig. 3. The effect of F_1, from Equations 7 and 2, is to produce the following stresses at "A":

$$\begin{aligned} (\widehat{rr}_A)_1 &= -\frac{F}{\pi hd} \qquad (\text{along } \overline{O_1A}) \\ (\widehat{\theta\theta}_A)_1 &= +\frac{F}{\pi hd} \qquad (\text{along } \overline{O_2A}), \\ (\widehat{r\theta}_A)_1 &= 0, \end{aligned} \tag{8}$$

and, from the action of F_2, we have as additional stresses at "A"

$$\begin{aligned} (\widehat{rr}_A)_2 &= -\frac{F}{\pi hd} \qquad (\text{along } \overline{O_2A}), \\ (\widehat{\theta\theta}_A)_2 &= +\frac{F}{\pi hd} \qquad (\text{along } \overline{O_1A}), \\ (\widehat{r\theta}_A)_2 &= 0. \end{aligned} \tag{9}$$

The boundary conditions require that $\widehat{NN}_A$ and $\widehat{TN}_A$ shall be equal to zero. To meet this requirement, for any case of disc loading, it is necessary and sufficient that

$$\sum_n [F_n \sin \sigma_n] = 0, \qquad \sum_n [F_n \cos \sigma_n] = 0. \tag{16}$$

The conditions imposed upon the problem by Equations 16 are not undesirable, inasmuch as they are simply the conditions which are always satisfied when the "n" applied loads are in static equilibrium. Thus we have shown that the successive application of the stress function defined by Equation 7 will enable us to determine the stresses in a disc or roller subjected to any number of concentrated radial loads. It should be particularly noted that, so long as Equations 16 are satisfied, the "n" loads may consist of any physically conceivable combination of tensile and compressive radial loads, which may have any spacing and any magnitudes.

The Cartesian components of stress are of principal interest to most designers. With the aid of the standard polar-to-Cartesian transformation, and the Equations 2 and 7, we can write the following equations for the total Cartesian components of stress at any point in the disc:

$$\widehat{xx} = \sum_n [\widehat{xx}_n] = \sum_n \left[f_n \left(1 - \frac{2R_n}{r_n} \cos^2 \psi_n \right) \right],$$

$$\widehat{yy} = \sum_n [\widehat{yy}_n] = \sum_n \left[f_n \left(1 - \frac{2R_n}{r_n} \sin^2 \psi_n \right) \right], \tag{17}$$

$$\widehat{xy} = \sum_n [\widehat{xy}_n] = \sum_n \left[f_n \left(- \frac{2R_n}{r_n} \sin \psi_n \cos \psi_n \right) \right].$$

In the above equations

$f_n = \dfrac{F_n}{\pi h d}$,

r_n = the distance from the point of application of F_n to the point for which the stress components are to be determined.

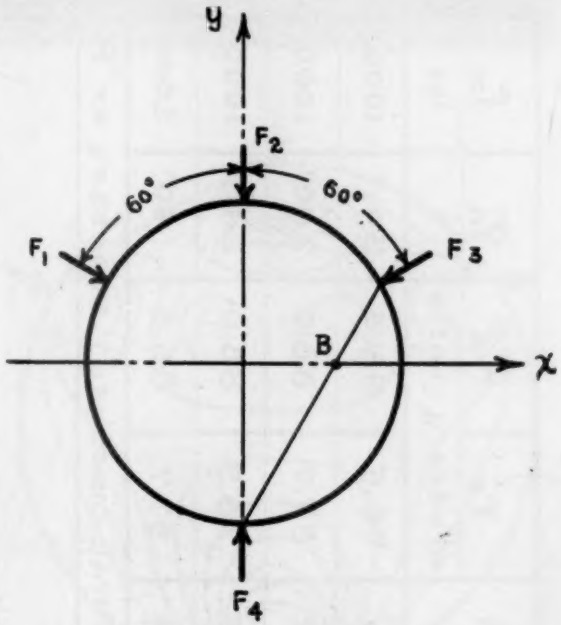
R_n = the distance from the point of application of F_n to the periphery of the disc along a line containing the point being analyzed,

ψ_n = the counter-clockwise angle between R_n or (r_n) and the positive x axis.

Only the function f_n is a function of the disc's diameter and consequently the data necessary for the evaluation of the remaining dimensionless expressions may be obtained from measurements made upon a drawing of any convenient scale. Although R_n and r_n may be measured in whatever units one wishes to use, d and h *must* be in inches if the Cartesian stress components are to be in lbs./sq. in. It is of particular importance to notice that no elastic constants appear in Equations 17 and therefore our method of analysis will apply to discs composed of any homogeneous and isotropic material.

As an example of the use of the Equations 17, let us determine the Cartesian components of stress at point "B" of the disc shown in Fig. 5. The problem is readily solved by tabu-

FIG. 5.



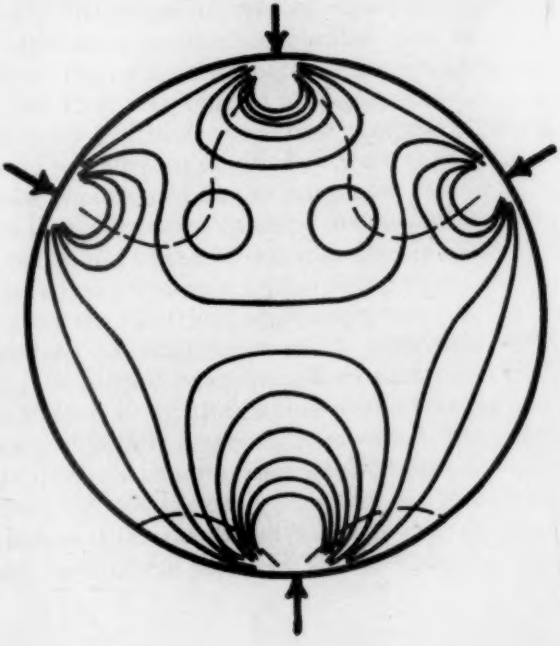
$F_1 = F_2 = F_3 = 2{,}000$ lbs.
$F_4 = 4{,}000$ lbs.
$h = 1/\pi$ in.
$d = 2$ in.

TABLE I.

n	r_n	R_n	ψ_n	f_n	$\hat{x}\hat{x}_n$	$\hat{y}\hat{y}_n$	$\hat{x}\hat{y}_n$
	arbitrary units			lbs	lbs/□"	lbs/□"	lbs/□"
1	76.5	98.3	341°	1000	-1290	+ 720	+ 800
2	57.7	86.6	300°	1000	+ 250	-1250	+1300
3	28.9	86.6	240°	1000	- 500	-3500	- 2600
4	57.7	86.6	60°	2000	+ 500	- 2500	- 2600
TOTAL COMPONENT STRESSES AT "B"					-1040	- 6530	- 3100
					→□←	↕□	↻□

FIG. 6.

FIG. 7.



lating first the required data and then the results of successive evaluations of Equations 17. This is done in Table I.

CONCLUSION.

Since experimental verification is of interest, and often a prerequisite to the acceptance of an analytical method, a photograph (Fig. 6) of the photoelastically determined isoclinics and isochromatics for a bakelite disc, loaded in the manner of the preceding example, is included for comparison with the corresponding analytically determined loci which are mapped in Fig. 7. The obvious agreement, coupled with the generality and simplicity of the author's analytical method, should establish it as a time and labor saving tool for the designer confronted by problems of this type. Applications of the method to analogous cases arising in the study of problems in electric or thermal flow will immediately suggest themselves to investigators in these fields.

CABLE DISCHARGES IN UNDERGROUND DUCTS.

BY

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and

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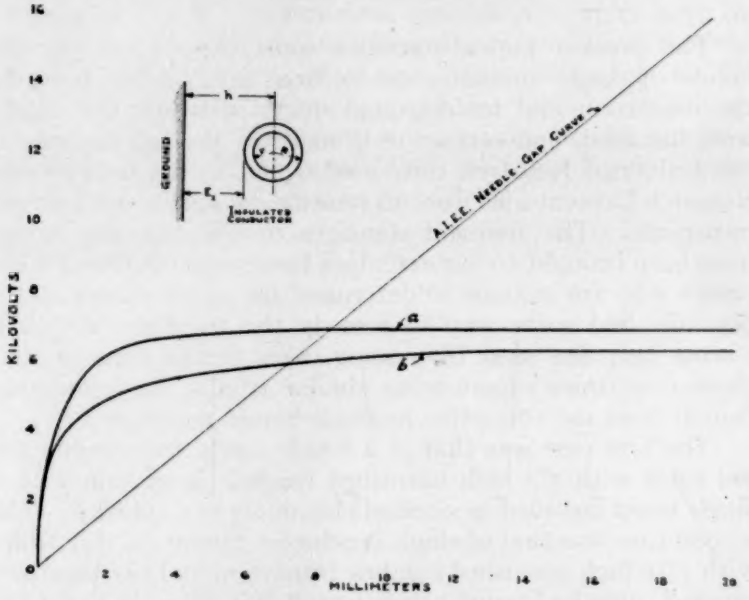
The present paper describes some experiences on the failure of single-conductor cables from arcs formed between the insulation and underground ducts in which the cables were installed, and certain tests made in the laboratories of the Universal Research Corporation and in the Continental Research Laboratories, Inc.. to remedy the source and prevent recurrence. The frequent damages to different size cables have been brought to our attention by several operating companies who are anxious to determine the exact causes and if possible, find some way to remedy the trouble. We shall discuss only the most interesting cases at this time so that those companies experiencing similar trouble may probably benefit from the corrective methods herein mentioned.

The first case was that of a single conductor 750,000 cir. mil cable with 7/8 inch varnished cambric insulation with a single braid installed in vitrified clay ducts in a subway. The second case was that of single conductor 750,00 cir. mil cables with 7/16 inch varnished cambric insulation and two weather-proofed cable-laid twine braids installed in fiber ducts for the leads of a 11,000 volt and a 13,200 volt generator. About four months after the electrical equipment was put into service on both systems, a lead from each generator was severely scorched. A careful examination in each case showed burns for several feet along the cables near the edges of the duct entrances. Further inspection revealed the burned areas being greatest on the external surface and tapering as each approached the conductors. A study of the condition of the cables showed that the cause was not due to poor or faulty insulation, nor to any moisture in the ducts.

In each case the cables were removed and tested, and evinced beyond reasonable doubt both audible and visible discharge at 3,800 volts, increasing to considerable intensity at 6,600 and 11,000 volts. The engineers from the power companies proposed several theories as to the cause of the trouble, but these did not stand up with our actual findings. A few other suggestions were made by the companies' engineers who assumed that probably the braid was wet, causing the charging current to leak out at points where the cables



were in direct contact with the ducts and, therefore, permitting these currents to burn the insulation. Another theory was based upon the belief that the phenomena could be assumed equivalent to the action of two large condensers connected in series, one consisting of varnished cambric as the dielectric, and the other having air as the dielectric. It was further assumed, if the braid were a perfect insulator, there might be a possibility of finding a number of air gaps between the braid and the duct that would be subjected to electrical potentials in excess of the dielectric strength of air. Consequently, if the

braid were able to conduct the charging currents, the points of expected contact with the duct would in all possibility reduce the voltage across the air-gaps so that no discharge could occur.

In order to simplify the air-gap conditions by illustration, Fig. 1 shows the critical values which may be compared with the A.I.E.E. needle-gap curve. Here we have shown by curve *a* which represents the potential stress across the air-gap between the ground and outside of the 750,000 cir. mil cable with 7/16 inch varnished cambric insulation, what the result was after a constant voltage of 7,500 volts was applied between conductor and ground. Curve *b* represents the potential stress across the air-gap between the ground and outside of the 750,000 cir. mil cable with 7/8 inch varnished cambric insulation with a constant voltage of 11,000 volts applied between conductor and ground. Both curves *a* and *b* are plotted in accordance with the following equations:

$$C_1 = \frac{k_1}{2 \log \epsilon \frac{R}{r}}, \tag{1}$$

$$C_2 = \frac{k_2}{2 \log \epsilon \left(\frac{h + \sqrt{h^2 - R^2}}{R} \right)}, \tag{2}$$

and

$$E_2 = \frac{E_1 C_1}{C_1 + C_2}, \tag{3}$$

where C_1 is the capacity per unit length between the conductor and outside of cable, C_2 is the capacity between outside of cable and the ground, E_1 the potential of conductor to ground, and E_2 the potential outside of cable to ground. k_1 denotes the dielectric constant of varnished cambric at 4.6, and k_2 the dielectric constant of air at unity.

However, to arrive at a satisfactory explanation of this phenomena, we decided to apply various tests on the injured cables and also on others having braids of different resistances. Several cables of the same size and thickness of insulation as the damaged conductors, but wrapped with one, two, three and four cotton braids with a flame-proof finish on each pro-

vided an audible and visible discharge beginning at about 9,000 volts on increasing voltage, and continuing on decreasing potential to about 7,500 volts. Other tests at potentials of 18 kv. for a period of 24 hours indicated to our engineers and physicists that any discharge occurring at normal operating potential of 11,000 to 15,000 volts, was practically insufficient to injure the cables, especially under those conditions in which the damaged conductors were found.

A series of new tests were subsequently carried out on the same cables which were then coated in sections with high resistant paints, among them being aluminum and graphite, each mixed with 20 per cent. of Zapon. The results obtained from these tests showed that the aluminum paint had a resistance of about 260,000 ohms per foot, the graphite coating had 2 ohms in every 6 inches, and the original two braids had about 110,000 megohms per foot. A final check on the experimental tests of these two coatings revealed that potentials as high as 16,000 volts could be safely applied before any audible or visible discharge was observable. It was finally decided to install one cable with uncoated flame-proof braids, and one cable with aluminum-zapon paint. Both cables have been in service now for the past two years without giving any trouble. It is the general belief among the operating engineers concerned that cables with a perfect flame-proof braid, operating at from 7,500 and 11,000 volts to ground will not be subject to similar current discharges.

In the past nine months, about ten other cases were brought to our attention where cables with weather-proof braid were destroyed, due to intense discharges occurring between the braids and underground ducts. In one serious case involving a 1,000,000 cir. mil cable, it was decided to wrap tightly a single layer strip of metallic tape around the insulation followed by a layer of friction tape and then coated with Zapon compound. The results were very satisfactory, since the cable was recently tested again and found to produce no sheath currents even when grounded at both ends.

In more recent tests on 1,000,000 and 2,000,000 cir. mil cables with 13/32 inch and 15/32 inch varnished cambric insulation, each cable had one layer of tape and a single weather-proof braid. A discharge began between the braid

and ground at about 10,000 volts in each cable. At a potential of 20,000 volts, a very pronounced discharge was observed from each cable which in all probability, would have damaged them both if the applied voltage had been continued. The discharges from both cables appeared to be at an air-gap of about three-tenths of an inch. In two other sections of these cables there was a layer of tape and a Seine twine braid with a flame-proof finish. These two cable sections were tested separately and each had a pronounced discharge at 5,000 volts, and at 23,000 volts both cables discharged on a 15/16 inch air-gap. From our experience with these two cables it was apparent that neither would be satisfactory for constant operation above 4,500 volts to ground. Another section of the 1,000,000 cir. mil cable had a layer of tape and asbestos braid with a flame-proof finish, and when this portion was subjected to a test it showed a slight discharge at one thread at 7,500 volts, and a very mild discharge at 23,000 volts.

In summarizing the results obtained from numerous experiments carried out, it appears that great care must be exercised in using certain ducts and single-conductor cables with Seine twine weather-proofed braids at operating voltages above 4,400 to ground unless a metal tape is employed. As an alternative for certain conditions, the braid can be made conductive by applying a coat of metallic paint. Past experience shows that no trouble has been encountered with cables possessing cotton braids with a reliable flame-proof finish. A number of indications point to the highest satisfaction already obtained by using asbestos braids with a flame-proof finish, or a coat of Zapon compound. Where metal tapes have a superior advantage over flame-proof or asbestos braids in completely eliminating a corona discharge, they are nevertheless objectionable, due to the formation of ozone in the ducts. This is borne out in several instances where metal tape was previously used on 250,000 and 500,000 cir. mil cables installed in fiber and vitrified clay ducts in which, an intense corona was observed.

While it has been customary for power companies to use lead sheath on cables or even to mount conductors on insulators, nevertheless, these arrangements may be warranted in such cases, which require cheaper construction. However, it

is possible to purchase cables with a good insulation without resorting to the use of lead with the accompanying difficulties of sheath currents, and the additional expense of potheads. Where flame-proofed asbestos braid may be unwarrantable, there are cases where weather-proofed braid is desirable and yet dependable. According to the remarkable results we have so far obtained, it is advisable to use a braid which can be treated and made sufficiently conducting as we have herein described, to prevent potential gradients that are destructive to the cables. A complete report on the present group of cables under investigation will be given in a future paper, which also will contain information on those cables now in service.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RESEARCH ON FLUID METERS, PARTICULARLY FLOW NOZZLES.

Over a year ago the subcommittee on the use of nozzles, orifices, and venturis of the American Society of Mechanical Engineers' committee on power test codes, requested the society's special research committee on fluid meters to furnish it with authoritative information on the designs in use, methods of using, and the constants of fluid meters employed as head meters for testing power plant equipment, such as turbines, fans, and blowers.

On carefully considering the problem, the fluid meters' committee felt that, while it had available sufficient information on orifice meters, more data were needed on flow nozzles and to a certain extent on venturis. The committee, therefore, decided that a research program should, if possible be undertaken on flow nozzles and venturis, to be tied in, wherever feasible, with orifices. The following conditions, however, were laid down.

1. That the program, if undertaken at all, should be sufficiently thorough and of wide enough range to insure real value of the results for many years.

2. That the planning and coördination of the tests, regardless of where they might be made, and the correlation of the results should be under the immediate direction of one person.

3. That existing plant facilities (including personnel) should be utilized as far as possible, so as to keep the cost of the work down and to insure a wide range of conditions.

It was likewise felt that if the results were to be of maximum value the tests should be made with pipe ranging from about 1 or 2 inches to 16 inches in diameter; the ratios used should range from about 0.1 to about 0.85; and as far as possible or desirable the tests should be made with water, steam, and air. Also, each differential producer should be tested over a Reynolds' number range of at least 1 to 5.

* Communicated by the Director.

Assuming that a research program of this extent could be carried through, H. S. Bean, chief of the gas measuring instruments section of the Bureau, was asked to undertake its direction, in accordance with recommendation 2.

In order to comply with the third recommendation it was necessary to collect information on the facilities available. To this end a circular letter was sent by Mr. Bean to those organizations believed to have suitable facilities, such as universities, electric utilities companies, natural gas companies, and meter, engine, and compressor manufacturers. The questions asked were the following:

1. Are you making any tests on flow nozzles or venturis at the present time?

2. If so, would you be willing to make the results of such tests available to the fluid meters committee so that they may be included and correlated as a part of the committee's program?

3. If the answer to 2 is affirmative, will you give an outline of your test program?

4. What equipment and facilities do you have that might be made available to the committee for making some of the tests proposed:

(*a*) tests with water
(*b*) tests with steam
(*c*) tests with air

In answering give information as to the size and maximum lengths of straight pipes that could be obtained, the source of the fluid flow, the approximate range of rates of flow, and the facilities for weighing the discharge when water or steam is used as the fluid.

5. To what extent would members of your staff be able to assist in any tests that might be made at your plant?

6. Have you suggestions as to the conditions that should be covered by the committee in this program of tests?

The following brief summaries indicate the gratifying nature of the replies received:

Public Service Company of New Jersey, Essex Generating Station, can make tests with water, using 6 to 16 inch pipe, 40,000 to 650,000 lbs./hr., up to 600 ft. head. Has two scale tanks, capacity 11,000 lbs. net, each.

University of California, Department of Mechanical Engineering, can make tests with water, using pipe up to 8 inches diameter; flows up to 3.4 cubic feet per second. Has a volumetric tank with a capacity of 400 cubic feet.

Bailey Meter Company can make tests with water, using 2 to 6 inch pipe (inclusive); flows up to 2,000 gallons per minute; 50 ft. head. Has a volumetric tank and a V-weir.

General Electric Company, Lynn Plant, can undertake work on steam and air, using 2 to 6 inch pipe; steam flows up to 25,000 lbs./hr. Has suitable condenser and weighing tanks.

Buffalo Forge Company can make tests using air, with pipe sizes up to 36 inches at low pressures; flows up to about 8 $ft.^3/sec$.

Favorable replies have likewise been received from the Massachusetts Institute of Technology, Ohio State University, the University of Pennsylvania, and others. The Bureau, itself, will work with water, air, and steam, for the most part using the facilities available in its hydraulic laboratory. Some funds are now available, and it is expected that enough more will be contributed to make possible carrying out the program practically along the lines originally laid down. Diameter ratios from 0.10 to 0.85 in at least four and possibly seven sizes of pipe from 2 to 16 inches in diameter, will probably be used. Each differential producer will be tested with water in one or more of the laboratories named. Check tests will be made using air and steam on from one-third to one-half the total combinations. Definite plans have been made covering tests of nozzles and taps and also for certain subsidiary tests.

It is expected that the program will require about three years for completion.

FUSIBLE TIN BOILER PLUGS.

The general rules and regulations of the Bureau of Navigation and Steamboat Inspection of the U. S. Department of Commerce require that the boilers of all steam vessels under the jurisdiction of the Bureau shall be provided with fusible

plugs as a safety measure. These fusible plugs consist of a bronze casing the tapered bore of which is filled, from end to end, with pure tin. The plugs are required to be inserted into the boiler shells, tubes, or flues, depending upon the type of boiler, so that the end of the tin filling on the water end of the plug is not less than 1 inch above the dangerous low-water level of the boiler. The plugs are intended to function as pressure-relief valves when the temperature within the boiler rises above the melting point of the tin filling. The melting point of pure tin is 232° C. (449° F.).

The regulations provide that the manufacturers of such plugs furnish, for examination and test, one sample from each lot of 250 plugs, or fraction thereof, and that no plugs of any lot shall be distributed for use until a certificate of approval has been obtained from the Bureau of Navigation and Steamboat Inspection.

The examinations and tests of the samples submitted are made by the National Bureau of Standards for the Bureau of Navigation and Steamboat Inspection. Chemical analysis of the tin filling is made to determine whether the purity of the tin conforms to the requirements of the regulations which prescribe that the tin shall contain not more than 0.50 per cent. of copper, and not more than 0.10 per cent. each of lead and zinc; or not more than 0.70 per cent. of total impurities.

Although it is possible to obtain tin of higher purity than that prescribed above, it has been found that a certain amount of contamination of the tin in the filling by the metal of the casing is unavoidable if the plugs are properly manufactured according to the regulations. It has been found also that satisfactorily constructed plugs will function in the desired temperature range if the tin of the filling does not contain impurities in excess of the amounts specified.

The plugs are examined also to determine that the tin fillings are metallically bonded to the casings and that the bores of the casings are tapered uniformly and smoothly from end to end. A recess in the bore of the casing, designed to hold the filling when it is not metallically bonded to the casing, is not permitted.

The following publications from the National Bureau of Standards describe studies, made over a period of years, of

various problems concerned with the manufacture and testing of fusible boiler plugs.

1. An investigation of fusible tin boiler plugs. G. K. Burgess and P. D. Merica. Tech. Pap. BS, **15** (1915); T53.

2. Tin fusible boiler plug manufacture and testing, published in Trans. Am. Inst. Min. & Met. Engrs. **64**, 227 (1920).

3. Reliability of fusible tin boiler plugs in service. J. R. Freeman, Jr., J. A. Scherrer, and S. J. Rosenberg. B. S. J. Research, **4**, 1 (1930); RP129.

DEFINITIONS OF POWER, POWER FACTOR, AND RELATED QUANTITIES.

Electrical energy is now one of the important articles of commerce and problems connected with its generation, transmission, and distribution are taxing the ingenuity of experts. In discussing these matters, it is important for all engineers to use the same language. However, in the complex conditions that have arisen, a group of engineers has frequently adopted a jargon which could not be understood by those even in nearly related fields. An effort is being made by the American Institute of Electrical Engineers to remedy this condition. In a paper published in the April number of *Electrical Engineering*, the Bureau has endeavored to amplify and clarify the definitions that have been prepared for the various power quantities which are connected with the rate of flow of energy in alternating-current circuits.

The definitions of the power quantities for a simple circuit with the most ideal type of alternating current are universally accepted. However, as the circuit becomes more complex or as the alternating current departs from the ideal, an extension of the definitions is required and new quantities, with their definitions, must be introduced. This paper outlines the principles by which these extensions can be made, and suggests names for all the required quantities.

EVOLUTION OF HYDROGEN SULPHIDE FROM RUBBER DURING VULCANIZATION.

The evolution of hydrogen sulphide from rubber during and subsequent to vulcanization has been dealt with previ-

ously (*BS. J. Research*, **4**, 501; April 1930 (RP162) and **9**, 163; August 1932 (RP464)). Further work has shown that the quantity of hydrogen sulphide evolved is dependent on its concentration in the rubber.

This is demonstrated by two vulcanization experiments which were conducted with a stock consisting of fine Para rubber, 68 parts, and sulphur 32 parts, by weight. In one experiment a weighed sample was cured in a vulcanizing press at 148° C. (298° F.) in the form of a sheet about 1 mm. thick and 250 mm. in diameter. The sample was protected by aluminum plates so that only the 1-mm. edge was exposed to the air. The sample was removed from the press at intervals and weighed, along with the aluminum plates which adhered to it. A relatively small, and progressive loss in weight was observed, which, on the basis of other work, was taken as being all hydrogen sulphide. At the conclusion of the experiment the aluminum plates were stripped off and the sheet of hard rubber was heated in air at 95° C. (203° F.) under a fan for one-half hour to drive off any hydrogen sulphide dissolved in the rubber. The loss in weight resulting from this treatment was only 0.025 per cent. of the weight of the sample.

In another experiment a sample of the same stock was extruded in a layer about 1 mm. thick on No. 12 aluminum wire. Vulcanization was conducted at 148° C. in a stream of inert gas, and the hydrogen sulphide determined by absorption in alkali as in research paper RP464.

The results of the two experiments are given in the following table:

Time Hours.	Total Hydrogen Sulphide Evolved. Sample in Press Per Cent.	Sample in Stream of Inert Gas Per Cent.
1	0.003	0.031
4	.020	.47
11	.030	—
22	—	1.58
25	.045	—
26	—	1.85
32	.099	—
40	.188	—
47	.295	—
50	—	3.06

A comparison of the second and third columns of this table indicates that much less hydrogen sulphide is evolved when hard rubber is vulcanized even in a partially inclosed space than when it is vulcanized in a stream of gas in which the hydrogen sulphide is swept away as fast as it is formed.

BUSY YEAR PLANNED FOR PAPER SECTION.

With the assistance of funds from other Government agencies and from outside organizations, the Bureau plans to expand the research activities of its paper section during the ensuing year.

A new project recently initiated is a study of the possible effect on papers, of fumigating gases used to rid written and printed materials of destructive insects. This was undertaken at the request of the National Archives and with their financial assistance. Another investigation which will take the section into a new field, is concerned with the stability of prints on motion picture films. This form of record material has assumed great importance; librarians, educators, and others interested in the spreading and preservation of knowledge are deeply interested in the possibilities of film records. With the assistance of a fund granted for the purpose to the National Research Council by the Carnegie Foundation, it is planned to make a year's study of the resistance of the film records to various degrees of temperature, humidity, and light. It is hoped that this work can later be expanded into a comprehensive study of the many other problems concerning miniature records, and of problems related to sound recordings.

Direction of and participation in the standardizing activities of the T. A. P. P. I. paper testing committee will be continued. The committee has developed 37 standard testing methods and has 14 additional ones under development at the present time. An attempt will be made to produce a device for measuring in numerical terms the rate of failure of printed currency under conditions which result in appearance and loss of strength similar to those caused by actual service wear. This work is supported by the Treasury Department.

One of the continuous jobs of the paper section, and of the Bureau in general, is the development of the technical require-

ments of Government purchase specifications. This involves service as committee members and sometimes research to secure technical information not available. The standardization project on lithographic papers will be continued through at least a part of the year. This work has resulted in three publications relating to improvement of register in successive color prints, and another will be issued in the near future.

Extension of the work in this field is planned if sufficient funds become available for it.

While the experimental paper mill can be operated only intermittently (with the limited personnel available the mill operatives must not only make the papers but also test them), it is hoped that progress can be made in studying the relation of the papermaking materials both fibrous and non-fibrous, to the stability and strength of book papers. This will complete the general program of work of this kind related to the preservation of records, as similar studies of writing papers have been made.

GRANULOMETRIC COMPOSITION OF CEMENT.

Although a great deal of work has been done in other laboratories to determine the effect of fineness of grinding of cement on the properties of neat pastes, mortars, and concretes made therefrom, nevertheless there has not been enough data available to allow many broad generalizations other than that fineness of grinding is an important factor in determining the rate of increase in strength, and that there is urgent need for further study. Therefore, an investigation has been undertaken at the Bureau with the hope of clearing up some of the controversial issues. In this study six different cements were separated into size fractions, and studies were made of the individual fractions as well as four different blends of them.

It was found in the study of the different fractions that the finest material in a cement, such as that of diameter less than seven microns, is very valuable because of the plastic qualities which it confers upon the concrete mixes and also because of the large contribution which it makes to the early strength. Materials of sizes larger than seven microns were found to be increasingly deficient in plasticity; a seven to twenty-two

micron fraction was not vastly different from an ordinary cement, while a fraction of material greater than fifty-five microns in diameter behaved very much like a fine sand. The strengths of mortar briquettes and concrete cylinders made from four fractions of material coarser than seven microns were found to decrease with increasing grain size, or to increase with increasing specific surface, at all ages tested.

Four cements blended from the fractions in varying proportions so as to have specific surfaces ranging from 1,350 to 3,300 cm.^{2}/g. developed strengths directly related to the specific surface at all ages. The neat pastes of these cements, on the average, required an amount of water for normal consistency almost directly related to the specific surface. The time of initial set as determined by the Gillmore needle was found to be inversely related to the specific surface.

A more thorough analysis of the strength data tended to prove that the compressive strength of concrete is very nearly a direct function of the amount of cement which has become hydrous. No direct measurements of the rates of reaction were made, but a function of size distribution was found which could logically be expected to represent the amount of cement which had become hydrous and which did yield values proportional to the strengths of the fractions and also those of the blends. When the compressive strengths were plotted against specific surface, one line was obtained for the blends and another for the fractions, but when they were plotted against the supposed hydrous material, only one line was obtained.

The contribution of the 0 to 7 micron fraction to the compressive strengths of the blended cements was calculated by an algebraic method based on the assumption that the contribution of any fraction to the strength of a blended cement is equal to the product of the decimal part of the blend composed of that fraction and the strength of the fraction when tested by itself. The calculated values were of the order which might have been expected, and it is believed that they indicate the actual worth of the fine material much more closely than values determined by testing the fraction alone with the low cement-water ratio which was required by the fine material.

A complete report of the work on this problem will be presented in RP777 of the *Journal of Research* for April.

EFFECT OF CALCIUM CHLORIDE ON PORTLAND CEMENTS AND CONCRETES.

During the past two years a fellowship had been maintained at the Bureau for studying the reaction of calcium chloride on portland cement and its constituents. A progress report on the reaction of calcium chloride on portland cement by Paul Rapp and Lansing S. Wells, giving the results of short-time tests of calcium chloride on certain physical properties of cement and concrete, was published in the Proceedings of the Thirteenth Annual meeting of the Highway Research Board, **13** (Part 1), 291 (Dec. 1933).

The long-time tests have now been completed and a final report of the investigation will appear as RP782 in the April issue of the Journal of Research under the title, "Effect of Calcium Chloride on Portland Cements and Concretes," by Paul Rapp. A paper by the same title will also appear in the Proceedings of the Fourteenth Annual Meeting of the Highway Research Board and will contain an appendix giving the complete data. Data are presented in these papers giving the effect of calcium chloride on the heat of hydration, setting time, strength and consistency of a selected group of cements. From measurements of temperature rise of a given amount of cement and water during the first 24 hours the quantity of heat evolved was calculated. The heat contributed by the individual compounds and the influence of calcium chloride on this heat was computed. The addition of calcium chloride appears to increase somewhat the heat contributed by dicalcium silicate and tetracalcium aluminoferrite and to decrease the heat contributed by tricalcium aluminate. There is little change in the heat contributed by tricalcium silicate when calcium chloride is added. Calcium chloride increases the rate at which the heat is evolved by all cements tested. A study of a large number of experimental cements showed that the addition of calcium chloride increased the strength contributing factors of the two calcium silicate compounds and decreased the strength contributing factor of tricalcium aluminate. The effect of calcium chloride on the strength contributing factor of tetracalcium alumino-ferrite is not readily apparent. The setting time of eleven commercial cements, together with the spread of the time of set of these cements, was decreased

as the amount of calcium chloride was increased. With each cement the flow, as determined with a flow table, was increased by the addition of calcium chloride. Calcium chloride added to mortar and concrete not only greatly accelerated the early strengths, but appreciably increased the one year strengths. These same effects were produced by the addition of calcium chloride to the sixty experimental cements. The optimum amounts to be added for different types of cement and at various curing temperatures is indicated.

Energy Expenditure in Household Tasks.—VENOVA W. SWARTZ (State Coll. Washington Agric. Exp. Sta. Bull., 282, 24 pages, 1933) has measured the human energy cost of certain household tasks. The subjects were women, between 19 and 33 years of age. The energy output was measured while at rest and while at work; the measurements were made by means of a Benedict knapsack apparatus; the oxygen consumed in a given period of time was determined; and the caloric output was calculated on the basis of the production of 4.825 large calories per each liter of oxygen (measured under standard conditions of temperature and pressure) consumed. In each experiment allowance was made for the body surface of the subject by expression of the result as calories per square meter of body surface per hour. The results were also calculated as the average percentage increase above the resting caloric output, in order to present the energy production due to work. This percentage increase in energy production in certain household tasks was:—Paring potatoes seated on a chair 43, seated on a stool 54, standing 50; washing clothes by hand 191; wringing clothes by hand 138, by hand-power wringer 197, by electric wringer 99; drying clothes in an extractor 125; rinsing clothes 161; putting up and removing the clothes line 135; hanging clothes with basket on floor 184, from utility table 118; emptying the washing machine 139; cleaning the laundry equipment 149; ironing napkins while standing with the ironing board in the normal position 82.2, with the board 2 inches above normal 77.1, with the board 4 inches above normal 70.2; beating a cake batter 51.5 to 54.8; kneading bread dough 116 to 133. Less energy was required in ironing while seated; the type of iron had but little influence on the energy requirement.

J. S. H.

NOTES FROM THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

EVIDENCE FOR A POSITRON-NEGATRON COMPONENT OF THE PRIMARY COSMIC RADIATION.*

BY

THOMAS H. JOHNSON.

Recent studies of the cosmic-ray shower intensities and their dependence on latitude, elevation and direction have brought forth some new results which seem to throw important light on the nature of the primary radiation. For measuring the intensity of showers, three coincidence counters were mounted with their axes horizontal and at the vertices of an upright equilateral triangle. Immediately above the upper counter was a lead plate 1.2 cm. thick and slightly larger than the cross-sectional area of a single counter. The counts thus recorded were corrected for accidental coincidences and the result was taken as a measure of the intensity of the shower producing radiation (I_s). The same three counters were also mounted in vertical line and the counting rate in this position, corrected for accidental coincidences and sidewise showers, was taken as a measure of the total radiation incident from the vertical direction ($I_\perp$). The ratio ($I_s/I_\perp$) of shower intensities to vertical intensities was thus independent of changes of sensitivity which might be feared in moving the apparatus from one station to another. The corrected rates and their ratios for six stations are given in Table I and they display the following interesting features. In the first place, the ratio ($I_s/I_\perp$) increases with elevation, showing that the showers are relatively more intense at high elevations. This agrees with the results of similar measurements [1] made in August, 1933, in Peru, and with the results of Rossi [2] in Erythrea. The second feature of interest is the

* *Physical Review*, February 15, 1935.

[1] T. H. Johnson, *Phys. Rev.*, **45**, 569 (1934).

[2] B. Rossi, *Ricerca Scientifica*, **5**, 594 (1934).

TABLE I.

Shower and Vertical Intensities.

Station.	Geo-magnetic Latitude.	Elevation (Meters).	I_s Shower Intensity (Counts per Min.).	$I_\perp$ Vertical Intensity (Counts per Min.).	$I_s/I_\perp$.
Swarthmore	50°	100	2.2	12.9	0.17
Vera Cruz	28°	20	2.3	11.9	0.19
Mt. Evans	50°	4300	15.0	36.8	0.41
Nevado de Toluca	29°	4300	11.4	28.2	0.40
Copilco	29°	2280	7.4	22.8	0.32
Parral	36°	1730	4.6	17.5	0.26

fact that at high elevations $I_s/I_\perp$ does not vary with latitude, and at sea level it decreases with increasing latitude. Thus the high elevation showers are due to primaries which are affected by latitude to about the same extent as the total vertical radiation, whereas the sea-level showers are due to rays of such energies that they are not affected by these changes in latitude to as great an extent as $I_\perp$.

A second series of experiments was carried out on Nevado de Toluca in Mexico in which a similar shower measuring arrangement was used for investigating the azimuthal symmetry of the shower producing radiation. To obtain better directional resolution the counters, in this instance, were placed at the vertices of an isosceles triangle, 23 cm. in altitude and 9 cm. base, with the same plate of lead over the upper counter and parallel to the base. In two runs this arrangement was inclined from the vertical 35° and 49°, respectively, and at regular intervals it was rotated about a vertical axis between the east and west azimuths. The results of these experiments are contained in Table II and

TABLE II.

Shower asymmetry on Nevado de Toluca. Elevation 4300 m., geo. mag. lat. 29°.

Zenith Angle.	$(I_w+I_e)/2$ (Counts per Min.)	$2(I_w-I_e)/(I_w+I_e)$
35°	3.70	0.012±.011
49°	2.50	0.018±.010
35° (without lead)	1.08	

they show that the shower producing radiation is almost completely symmetric about the meridian plane. For com-

parison it is noted that the total western radiation, measured with three counters in lines at the same station was 10 and 13 per cent. more intense than the eastern radiation at these same angles. It seems impossible to account for this symmetry by the failure of the apparatus to resolve directional effects since the shower intensities did show marked variation with the zenith angle. Also it was found by removing the lead that more than two-thirds of the counts recorded were due to showers produced in the lead and this presented a much larger area towards the azimuth in which it was pointing than to the opposite azimuth. Since shower intensities vary with latitude, they must be due to primary charged rays, and the azimuthal symmetry must mean that these are about equally divided between positives and negatives.

This suggests that the primary shower producing component consists of positrons and negatrons, while the radiation which produces the asymmetry measured by counters in line is due to more penetrating corpuscles, presumably protons. This is somewhat similar to the hypothesis proposed on other grounds by Compton and Bethe,[3] and is in line with the findings of Anderson, Blackett and others that the intermediate shower producing radiation probably consists of photons, for it is perhaps less difficult to account for the production of these photons by primary electrons than by protons. It is possible that some of the events which are recorded by the shower measuring arrangement can be produced by protons, and if so, these would represent a larger fraction of the total at sea level. This would seem to be the explanation of the asymmetry in showers found at sea level on the equator,[1] and of the slight asymmetry shown by the present measurements at high elevations in Mexico.

On the basis of the openings of the cones for rays of various energies, given in 1933 by Vallarta, the positive component alone seemed sufficient to account for the whole of the latitude effect.[1] The recent calculations of Lemaitre, Vallarta and Bouckaert,[4] on the other hand, give values for the openings of the cones such that the asymmetries and latitude effects

[3] A. H. Compton and H. A. Bethe, *Nature*, 134, 734 (1934).

[4] I am indebted to the authors of this paper for sending me the manuscript in advance of publication.

are consistent with the existence of a negative component as well. Estimates of the magnitude of this component will be made in a later publication.

These studies have been made with the support of the Carnegie Institute of Washington to which acknowledgment is made. I wish also to express gratitude to Mr. Lewis Fussell, Jr., for his help with the measurements and the reduction of data.

NORTH-SOUTH ASYMMETRY OF THE COSMIC RADIATION IN MEXICO.*

BY

THOMAS H. JOHNSON.

During a recent survey of cosmic-ray angular distributions, northern and southern intensities were compared at six different zenith angles in the plane of the local magnetic meridian. Measurements were made at two elevations in geomagnetic latitude 29°. The first station, referred to by the name Copilco, was on a ranch near Mexico City at an elevation of 2280 m. The second station was a camp on the summit of Nevado de Toluca, a volcano in the State of Mexico, elevation 4300 m.

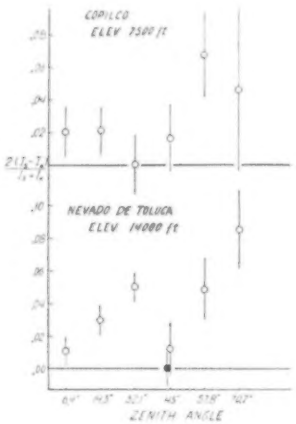
The apparatus used was a new multidirectional coincidence counter which simultaneously recorded the intensities from seven different zenith angles. (Because of high horizons the data for the lowest of these have not been used.) Frequent rotations of 180° about a vertical axis at regular intervals gave data for comparing the intensities from opposite azimuths at each of the zenith angles without relying upon long-time constancy of the instrumental sensitivity, nor upon knowing the relative sensitivities of different coincidence groups. The operation and recording were wholly automatic and it was only necessary to set up the apparatus and then afterwards to read the records.

The results of the north-south comparisons represent but a small part of the data obtained on the expedition, but

* *Physical Review*, January 1, 1935.

since they present some new and unusual features they are reported in advance of the complete account of the work. A definite southern excess was found at most zenith angles and at both stations. These are represented in Fig. 1, as the ratios of the differences of the south and north intensities to their average value. Each point in the figure is the average of many independent determinations, and from the dispersion of the individual data the probable errors can be determined with considerable accuracy. These are represented by the vertical lines. Data for angles near the horizon are characterized by a small number of counts and the probable errors

FIG. 1.



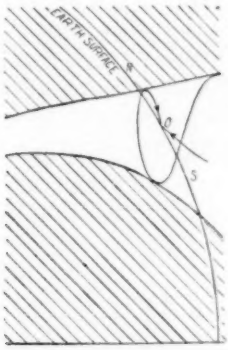
Ratios of the difference to the average of south and north intensities at two stations in Mexico.

are correspondingly large. The point represented by the full dot was obtained in the same latitude at an elevation of 11,000 ft. in 1932.

A north-south asymmetry of this general character was first predicted by Lemaitre and Vallarta, though the excluded region diagrams of Störmer give a basis for the qualitative explanation. If attention is limited to rays of a particular energy which arrive from a direction parallel to the plane of the meridian this fixes the scale on which to represent the radius of the earth and it fixes the shape of the excluded regions. The component of the motion of a charged corpuscle

resolved parallel to the meridian plane which rotates so as to always contain the corpuscle, is similar to that of a small ball rolling in the horn-shaped potential valley, a portion of which is represented in Fig. 2. To be incident from the polar side of the observer at angles close to the horizon, rays would have to first pass through the earth as is indicated by the diagram, whereas from the equatorial side the orbit comes directly from external space. A lower northern intensity can thus be interpreted as a shadow effect. Since other energies are also to be taken into consideration the shadow is only a partial one. These considerations seem to account for the asymmetry at angles close to the horizon but the

FIG. 2.



Portion of the Störmer excluded region diagram for rays incident in the magnetic meridian in the latitude of Mexico, showing typical orbits incident from the north and from the south at the same zenith angle.

asymmetry near the zenith would seem to require more complicated orbits which first enter the horn on the opposite side of the equator where they penetrate the earth, thence passing out again, crossing the equator, and arriving at the point *O*. Recent calculations by Lemaitre and Vallarta have indicated the existence of such orbits and it is possible that they may account for the observed asymmetry at angles close to the zenith. It would also seem possible to account for a dip in the asymmetry such as is observed at 45° by a consideration of these same orbits. However, it is possible, though not probable in view of the similar results at both stations, that this dip is due to statistical fluctuations.

If the north-south asymmetry is to be attributed to shadow effects, along the lines indicated, it should depend upon the sum of the positives and negatives, and not upon their difference as in the case of the east-west asymmetry. The effect should disappear at the equator and should appear as a northern excess in southern latitudes.

I am indebted to M. S. Vallarta for urging me to make these further studies of the north-south intensities, as well as for his coöperation in carrying out the work. I also wish to acknowledge my gratitude to Dr. C. S. Margain for the use of his facilities at Copilco, to the Federal Government of Mexico for assistance on Nevado de Toluca, and to Mr. Lewis Fussell, Jr., for his help with the measurements and reduction of data. The work was carried out under a grant from the Carnegie Institution of Washington, administered by the Cosmic Ray Committee and the Department of Terrestrial Magnetism.

THE ORIGIN OF THE HARDENING OF COSMIC RAYS IN PASSING THROUGH MATTER.*

BY

W. F. G. SWANN, Director

Let N_s be the rate of production of cosmic-ray showers of any given type per cc. per unit solid angle at some assigned angle θ to the vertical. In a recent communication,[1] the writer has developed the consequences of the assumption that N_s increases with the energy E of the primary rays more rapidly than would be represented by a linear law. For purposes of mathematical illustration the form

$$N_s = \alpha_1 E + \alpha_2 E^2 + \cdots \text{etc.} \qquad (1)$$

was assumed. It was supposed that the α's were functions of the atomic number of the medium and that for air, only α_1 was of importance. The fact that dE/dx is proportional to N_s leads to an exponential law for the decrease of energy in passing through the atmosphere, and so to an exponential

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* *Physical Review*, February 1, 1935.

[1] W. F. G. Swann, *Phys. Rev.*, **46**, 828 (1934).

law for the corresponding intensity of shower production. Moreover, the assumption that for high atomic numbers the terms of importance in (1) involve higher powers of E than the first lead to the conclusion that the rate of shower production in lead, for example, should increase with altitude more rapidly than the measured cosmic-ray intensity, a fact in harmony with the observations of T. H. Johnson,[2] B. Rossi and S. de Benedetti[3] and J. C. Street[4] on small showers, and with those of C. G. and D. D. Montgomery[5] and of R. D. Bennett, G. S. Brown and H. A. Rahmel[6] on showers of larger sizes, or Hoffmann Stösse as they are called.

All of this is for the case where the primary cosmic rays are of a uniform energy before entering the atmosphere, and where the measured cosmic-ray intensity is that produced by the showers initiated by the primaries whose directions of motion these showers perpetuate. It is the object of the present note to show that if we generalize the foregoing ideas to the case where even for air, the non-linear terms in (1) play a part, we obtain a type of variation of measured cosmic-ray intensity with altitude which departs from the first approximation of an exponential form in a manner in harmony with experiment.

Thus, if in general we write, for air,

$$N_s = f(E) \tag{2}$$

and if, in line with the assumptions of the former paper we assume that the energy is lost entirely by shower production, we have

$$dE/dx = -\beta N_s = -\beta f(E), \tag{3}$$

where dx is an element of length of path of the primaries. Hence,

$$-(1/N_s)(dN_s/dx) = -(dE^2/dx^2)/(dE/dx).$$

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[2] T. H. Johnson, *Phys. Rev.*, **45**, 569 (1934).

[3] B. Rossi and S. de Benedetti, *Ricerca Scient.*, **5**, 1 (1934).

[4] J. C. Street, as yet unpublished.

[5] C. G. and D. D. Montgomery, in a paper presented at the Pittsburgh meeting of the American Physical Society, December 27–29, 1934.

[6] R. D. Bennett, G. S. Brown and H. A. Rahmel, in a paper presented at the Pittsburgh meeting of the American Physical Society, December 27–29, 1934.

Since

$$d^2E/dx^2 = -\beta f'(E)dE/dx,$$

$$-(1/N_s)(dN_s/dx) = \beta f'(E). \qquad (4)$$

Now the left-hand side of (4) is the *apparent* coefficient of absorption μ which would be measured by an observer for any point if the observer assumed an exponential form $N_s = N_{s0}e^{-\mu x}$, and obtained μ by measuring the infinitesimal percentage change in N_s for a corresponding infinitesimal change in dx. We see that this apparent μ increases with E if $f(E)$ increases more rapidly with E than would be given by a linear law; for, in that case, $f'(E)$ will increase with E.

Hence, we see that the assumption of a *single* energy for the rays entering the atmosphere leads, on the foregoing views, to a decrease of intensity with depth below the top of the homogeneous atmosphere of such a nature that the apparent absorption coefficient μ decreases as we approach the earth, since E decreases with depth below the top of the atmosphere. This conclusion is in harmony with the apparent hardening of the rays as they pass through the atmosphere.

In the case where the medium is of high atomic number, and where, consequently, the nonlinear terms of (1) are more important than for air, the hardening should be more pronounced than for air. Thus, writing (4) in the form $\mu = \beta f'(E)$ and using (2), we have

$$(1/\mu)(d\mu/dN_s) = f''(E)/[f'(E)]^2.$$

Taking a case where $f(E) = \alpha_n E^n$,

$$(1/\mu)(d\mu/dN_s) = \alpha_n n(n-1)E^{n-2}\alpha_n{}^2 n^2 E^{2n-2}$$
$$= [n(n-1)/n^2]/\alpha_n E^n = n(n-1)/n^2 N_s.$$

Thus if $\delta\epsilon_\mu$ is the percentage change in μ corresponding to the percentage change $\delta\epsilon_N$ in N_s

$$\delta\epsilon_\mu/\delta\epsilon_N = n(n-1)/n^2.$$

Thus, if we measure the intensity of the showers emerging from a cylinder of lead for different thicknesses of the lead, the percentage change in μ per unit change of shower intensity caused by change in thickness should increase with n from

the value zero for n = unity to a maximum determined by n = infinity. In other words, the *hardening* of the rays as understood in the more exact sense exemplified above, should be greater in the case of lead than in that of an element of lower atomic number.

The whole of the foregoing discussion has been made in terms of a radiation having a definite and unique energy before entering the atmosphere; and its purpose is to show the extent to which the phenomena considered may be accounted for on the basis of such a simple hypothesis. The consequences here developed are, however, applicable in the case of a nonhomogeneous primary radiation, and the most natural conclusion would be to suppose that such nonhomogeneity was necessary, at any rate for the charged corpuscular part of the radiation, in order to account for latitude and directional phenomena. However, this is a matter which it is not my purpose to discuss here.

ON THE ELECTROSTATIC DEFLECTION OF COSMIC RADIATION.*

BY

W. E. DANFORTH and W. F. G. SWANN.

Early in 1933, we arranged an experiment to study the deflection of cosmic-ray particles by strong electrostatic fields between parallel plates. Previous magnetic deflection experiments had left, of course, no reason to doubt that an electrostatic deflection should exist. Our object was rather to determine the relative numbers of rays in the lower energy range. In April, 1933, a small effect had been observed and was mentioned by the senior author in a lecture before the National Academy of Sciences. An abstract of this lecture has appeared in *Science*.[1] Further observations, however, resulted in a diminution of the electrostatic deflection relative to the probable error so that a complete report was postponed pending more exhaustive investigations.

Recently Lenz [3] has reported electrostatic deflection re-

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* *Physical Review*, March 1, 1935.

[1] W. F. G. Swann, *Science*, May 19, 1933.

[2] E. Lenz, *Nature*, 134, 809 (1934).

sults of large magnitude and it becomes of interest to compare them with our own observations. We find it difficult to reconcile his large effects with the other existing data regarding the distribution of cosmic-ray electrons in energy. The considerations to be outlined here have led us to the conclusion that Lenz's low field-strength result is irreconcilable with our observations and that electrons of sufficiently small energy to have been deflected could not have penetrated the absorbing material present. Neither can we reconcile his large high field strength effect with the magnetic deflection result of Curtiss [3] nor with the cloud-chamber observations of Anderson.[4]

Lenz, Curtiss, and ourselves all used three or more Geiger-Müller counters in a vertical line with a region of deflecting field between two of them, and all found a diminution of counting rate when the electric or magnetic field was applied. Lenz's data with the bottom counter displaced will not be included in this discussion.

One of us [5] has computed, for each of the experiments, the fractional diminution (ϵ in the diagram) that would be observed if all the rays were of a given energy (V in the diagram). The actual diminution will be, of course, the integral of the product of ϵ by the energy distribution function. Table I shows the per cent. diminutions obtained in the four

TABLE I.

Curve.	Experiment.	% Diminution Obs.	Equiv. Abs. in Mm. of Lead.
a.....	Lenz 700 v/cm.	33%±7%	10
b.....	Swann & Danforth	3%±3%	7
c.....	Lenz 70,000 v/cm.	94%±2%	10
d.....	Curtiss	33%±2%	6

experiments and the amount of absorbing material, expressed in mm. of lead, associated with each.

Considering any two deflection experiments, the one

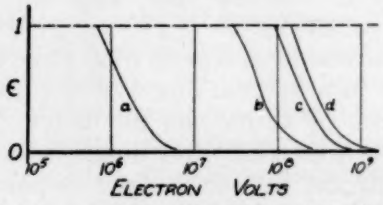
[3] L. C. Curtiss, *Bur. Standards J. Research*, **9**, 815 (1930).

[4] C. D. Anderson, *Phys. Rev.*, **43**, 381 (1933) and a paper now in process of publication in the *Proc. Roy. Soc.*

[5] W. E. Danforth, J. FRANK. INST., **217**, 331 (1934) and a paper now in preparation.

whose ϵ curve lies the farther to the right should give the larger effect. Comparing Lenz's 700 volt/cm. result with the authors', and his 70,000 volt/cm. result with Curtiss's, it appears from the curves that, as regards *a* and *b*, Lenz's 700 volt/cm. effect should be less than ours; and as regards *c* and *d*, his 70,000 volt/cm. effect should be less than that of Curtiss, whereas the reverse of these two conclusions is recorded. The diagram shows, further, that the electrons eliminated in Lenz's 700 volt/cm. experiment lie below 10^7

FIG. 1.



Fractional number (ϵ) of electrons eliminated by deflecting field as function of their energy.

volts, but Anderson's data indicate that such electrons cannot penetrate 10 mm. of lead. Also, Lenz's 70,000 volt/cm. result requires that at least 94 per cent. of the particles lie below 10^9 volts while Anderson reports 25 per cent. lying above 4×10^9 volts.

Curtiss worked under a thin roof while both Lenz and the authors had two concrete floors above them, but this could hardly produce sufficient differences in energy distribution to explain the discrepancies. And the difference in amounts of absorbing material inherent in the three counter systems are in the wrong sense to resolve the difficulties.

THE ENHANCEMENT OF COSMIC RAY NUCLEAR BURSTS BY THE PRESENCE OF SUBSIDIARY MATERIAL.*

BY

C. G. MONTGOMERY, D. D. MONTGOMERY and W. F. G. SWANN.

It has been pointed out [1, 2] that cloud chamber photographs of showers of rays strongly suggest that a shower

* *Physical Review*, March 15, 1935.

[1] W. F. G. Swann, JOUR. FRANK. INST., **218**, 173 (1934).

[2] C. G. Montgomery, *Phy. Rev.*, **45**, 62 (1934).

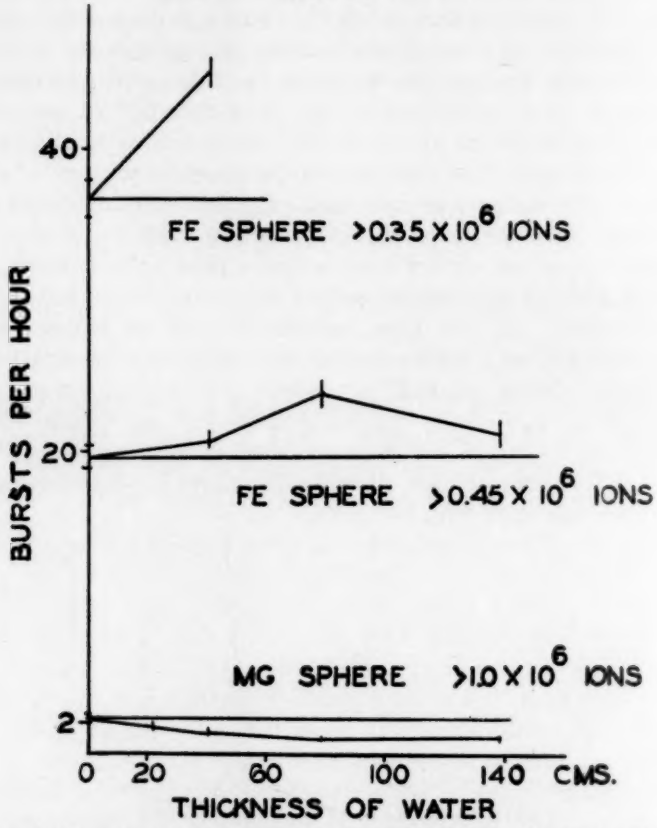
contains radiation which has the power of creating another shower. Hence it should be possible for the radiation accompanying a shower formed in one body to produce a shower in another body. An experiment to show this phenomenon has been performed. As the first body the water contained in a tank 126 cms. in diameter and 150 cms. high was employed. Seventy-five centimeters below the tank was placed the second body: a spherical ionization chamber of cast steel of 2.5 cms. wall thickness and 14.2 liters capacity, filled with nitrogen to a pressure of 12.5 atmospheres. The number of bursts of ionization greater than 0.45×10^6 ions occurring in the chamber was measured for different thicknesses of water. As the depth of the water was increased, the number of bursts first increased, so that at a thickness of 79 cms. of water, the number was about 20 per cent. greater than at zero thickness. At still greater depths of water, the number of bursts decreased, until, at 136 cms., approximately as many bursts were observed as at zero thickness. This is represented by the center curve of Fig. 1. Some observations were also taken with a slightly higher sensitivity in which bursts greater than 0.35×10^6 ions were measured. The increase between zero and 41 cms. of water for these bursts is shown in the upper curve of Fig. 1.

At first glance, the simplest interpretation of these data would seem to be that the additional bursts observed when water was present were bursts of ionizing rays originating in the water and passing through the walls of the ionization chamber despite the large intervening thickness of water and iron. However, when an ionization chamber with one centimeter magnesium walls was substituted for the steel one, the number of bursts decreased uniformly as the depth of the water was increased. This data is shown in the lower curve in Fig. 1. The magnesium chamber had a volume of fifty liters and was filled with nitrogen to a pressure of 14.5 atmospheres. In order to compare its results with those obtained with the steel chamber, bursts of a somewhat larger size should be considered. The size of burst in the magnesium sphere comparable to 0.45×10^6 ions in the steel chamber is 0.78×10^6 ions if we suppose the ionization per centimeter of path should be the same, and 1.84×10^6 ions if the ionization per unit volume should be the same in the two cases. A

value between these two, viz., 1.0×10^6 ions, has been chosen for the purposes of this comparison.

The uniform decrease in the number of bursts observed with the magnesium chamber obviously represents the ab-

FIG. 1.



The rate of occurrence of bursts of ionization in chambers placed below different thicknesses of water. The vertical lines at the observed points represent the standard deviation in the rate, computed from the square root of the number of bursts observed.

sorption of the primary burst-producing rays. It is of the order of magnitude to be expected from the variation with altitude of the number of bursts in this chamber.[3] There is no evidence of the three or four bursts per hour coming from

[3] C. G. Montgomery and D. D. Montgomery, *Phy. Rev.*, **47**, 429 (1935).

the water whose occurrence the data taken with the steel chamber seem to indicate. Thus we must conclude that the additional bursts in the steel chamber originate in its walls, but are occasioned by the presence of the water. The eventual decrease in the number of bursts with increasing thickness of water represents here also the absorption of the primary burst-producing rays.

The initial increase in burst frequency must be produced by some kind of radiation coming from the water. That this radiation is accompanied by a shower of ionizing rays is evidenced by the following experiment. Three Geiger-Mueller counters, each of area 109 square centimeters, were placed below the water tank and above the steel sphere in such positions that they would only be simultaneously discharged by at least three ionizing rays. The simultaneous discharges of these three counters were made to light a small lamp which made a trace on the same photographic paper on which was recorded the occurrence of the bursts of ionization. Thus the simultaneous occurrence of a burst and the discharges of the three counters could be recognized. With 41 cms. of water in the tank, observations were taken for a period of 10.8 hours. During this time 69 simultaneous discharges of the counters occurred, and 19 of these were coincident with the occurrence of a burst of ionization greater than 0.35×10^6 ions in the steel chamber. Thus the radiation from the water which will produce bursts in the steel chamber walls is accompanied by a shower of ionizing particles.

The authors wish to acknowledge gratefully the financial support of the American Philosophical Society in these experiments.

THE ANNIHILATION OF THE PROTON.*

BY

ARTHUR BRAMLEY.

The experiments of Anderson, Millikan, Neddermeyer and Pickering[1] and Gilbert,[2] on the production of showers indi-

* *Physical Review*, September 1, 1934.

[1] Anderson, Millikan, Neddermeyer and Pickering, *Phys. Rev.*, **45**, 352 (1934).

[2] Gilbert, *Proc. Roy. Soc.*, **A144**, 559 (1934).

cates that the immediate cause of the spray of negative and positive electrons observed in cloud photographs of the showers are gamma-rays. The high energy gamma-rays on striking a nuclear field lose their energy by generating a number of high energy pairs, negative and positive electrons. The origin of these hard gamma-rays is obscure. Experiments indicate that these high energy photons are probably not produced by electrons impinging on the nucleus. There then remains the possibility that their formation arises from the annihilation of matter, in a somewhat similar way to that suggested by Jeans [3] in his paper on the origin of cosmic rays. We shall give in this note an approximate expression for the probability $P(\eta)$ of the following process. A high energy proton strikes a nuclear Coulomb field of atomic number Z and is converted into a gamma-ray and a positive electron of energy ηc.

In treating this problem we have followed the method suggested by Fermi for the analysis of the beta-ray problem. We shall suppose that the wave function μ of the proton is changed into the wave function ϕ of a neutral particle and at the same time a positron and a photon of the energy $h\nu$ appear in the field. According to Heisenberg we should consider the proton and the neutral particle as two separate states of the particle described through an inner coördinate ρ:

$$\rho = +1 \quad \text{for the neutral particle,}$$
$$\rho = -1 \quad \text{for the proton.}$$

The passage from the proton to the neutral particle is determined through the operators $Q = \begin{vmatrix} 0 & 1 \\ 0 & 0 \end{vmatrix}$ and $Q^* = \begin{vmatrix} 0 & 0 \\ 1 & 0 \end{vmatrix}$ which operate on the coördinate ρ appearing in the Hamiltonian of the proton and the neutral particle. The Hamiltonian function for the problem is composed of three terms, the energy H_1 of the proton and neutral particle, the energy H_2 of the photon and positron and finally the coupling energy between the two sets of particles, H_3

$$H_1 = (1 + \rho)N/2 + (1 - \rho)P/2,$$

[3] Jeans, *Nature*, 116, 861 (1925).

where N and P are the energy operators for the neutral particle and proton, respectively. The wave functions for the positron in the central field Ze are designated by the symbol ψ_s. In carrying out the calculations, the vector potential a of the radiation field is analyzed into a system of plane waves $a = \Sigma_i q^i a_i$. We shall assume, following Fermi, that the coupling term is effective only at small distances and can be represented by the expression

$$H_3 = g\{Q\psi(x)\phi(x) + Q^*\psi(x)\phi(x)\} - e(\alpha a),$$

where the coördinates of the proton and neutral particle are taken at the position of the proton. If the proton changes into a neutron and positron the neutron represents one of the neutral particles, but if the mass of the proton is annihilated we shall assume the neutral particle is a neutrino. We have attempted in this way to give a mathematical description of a process which we recognize may be only crudely represented by such a mechanism. In the annihilation problem the failure of the conservation laws will be taken care of by the energy given to the neutrino.

On the basis of calculations performed with this Hamiltonian, we have arrived at the following results. The positrons are distributed in energy near their maximum energy $\eta_0 c$ according to a law very similar to that with which we are familiar in the beta-ray emission from radio-active nuclei in the same region. The total probability of annihilation per nucleus $P = \int_0^{\eta_0} P(\eta)d\eta$ where $\eta_0 c$ is the maximum energy possible for the positron, varies as $(\eta_0)^5$ and is practically independent of the atomic number of the nucleus with which it collides.

The accuracy of these results is limited by a number of considerations: (1) the field of the nucleus is not represented by a Coulomb field for all distances; (2) the wave functions for the nucleus is unknown; (3) the interaction of the positron and neutrino has been taken in a form similar to that given by Fermi in his treatment of the beta-ray spectrum. All these difficulties appear in the current theories of the beta-ray spectrum of the radio-active elements;[4] and finally (4) the

[4] Fermi, *Zeits. f. Physik*, **88**, 161 (1934); Bramley, *Phys. Rev.*, **45**, 901 (1934); Tamm, *Nature*, **133**, 981 (1934); Iwanenko, *Nature*, **133**, 981 (1934).

change of a proton into a positron and neutrino is taken as the representation of the annihilation of the proton. Processes in which such a large change in mass occur may possibly not be represented by such simple quantum mechanical considerations. However, the agreement of the theory with experiment in the case of the beta-ray spectrum makes us hopeful that this theory of the annihilation of the proton may fairly well represent the facts.

According to these ideas, part of the primary cosmic rays are protons which, on striking the outer atmosphere, are converted in the majority of cases into a photon and a positron. Until the proton strikes a nucleus and is converted into a photon and a positron, it loses its energy gradually by primary ionization along its path. As we have mentioned, the probability of this type of collision in which there occurs the annihilation of the mass of the proton, is proportional per nucleus to the fifth power of the maximum energy possible for the positron, but is independent of the atomic number of the nucleus with which it makes the collision. The secondary gamma-rays produced in this collision and which are responsible for the showers, should be absorbed per nucleus proportionally to the square of the atomic number of the nuclei in the medium in which the showers are produced. However, the rate of absorption of these gamma-rays should be independent of their energy.[5] The observations of Kunze [6] on the rate of ionization of the high energy particles in cosmic rays support the view that these particles are protons.

A CIRCUIT FOR THE ANALYSIS OF GEIGER COUNTER PULSES.*

BY

W. E. RAMSEY and M. R. LIPMAN.

In many investigations involving the use of Geiger counters it is important to know, not only the way in which the counting rate varies with the voltage of the counter, but also the sizes of the pulses, the time of recovery and the form of the recovery curve. The circuit described here was

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* *Review of Scientific Instruments*, April, 1935.

[5] Oppenheimer and Plesset, *Phys. Rev.*, **44**, 53 (1933).

[6] Kunze, *Zeits. f. Physik*, **83**, 1 (1933); Williams, *Phys. Rev.*, **45**, 729 (1934).

designed primarily to provide a rapid means for measuring these latter characteristics. In addition, it was intended to provide a method for studying directly certain other phases of the discharge phenomena in counters. The arrangement is essentially one in which the current through a galvanometer is zero when the input grid potential is greater than a certain value, which we have called V_0', and finite and constant for potentials less than this value.

If the central wire of a Geiger counter is connected through appropriate resistances to this grid, changes in the potential of the wire will produce proportional changes in the grid potential. In a counter breakdown, the wire suddenly achieves its maximum negative value and then slowly returns to its original potential. We may, by adjusting the bias on the grid, assign the potential of the counter wire for which our grid passes through the value V_0'. We then observe a ballistic throw of the galvanometer which is proportional to the time that the potential of the counter wire is more negative than this assigned value. A series of such assigned values and the times associated with each, provides all the data necessary for the construction of the recovery curve of the counter.

While a cut-off characteristic may be achieved in a number of ways employing vacuum tubes, the circuit described here provides many desirable features of stability and convenience.

Figure 1*A* is a diagram of the circuit, and Fig. 1*B* shows the characteristic with which we are concerned. V' is the input potential on the grid of the first tube and I_M is the output current passing through the galvanometer M. If a negative pulse on the grid of the first tube causes V' to change from a value greater than V_0' to a value less than V_0', I_M increases sharply to a definite value of 28 milliamperes. This current continues to flow with unchanged value for any time which is short compared to the time constants of the grid circuits of the last three tubes. Therefore, if V' remains less than V_0' for a length of time τ, a quantity of electricity passes through M equal to $2.8 \times 10^{-2}\ \tau$. This quantity gives a ballistic throw which is proportional to τ, providing τ is short compared to the period of the galvanometer. In practice, τ is rarely greater than a hundredth of a second, and the

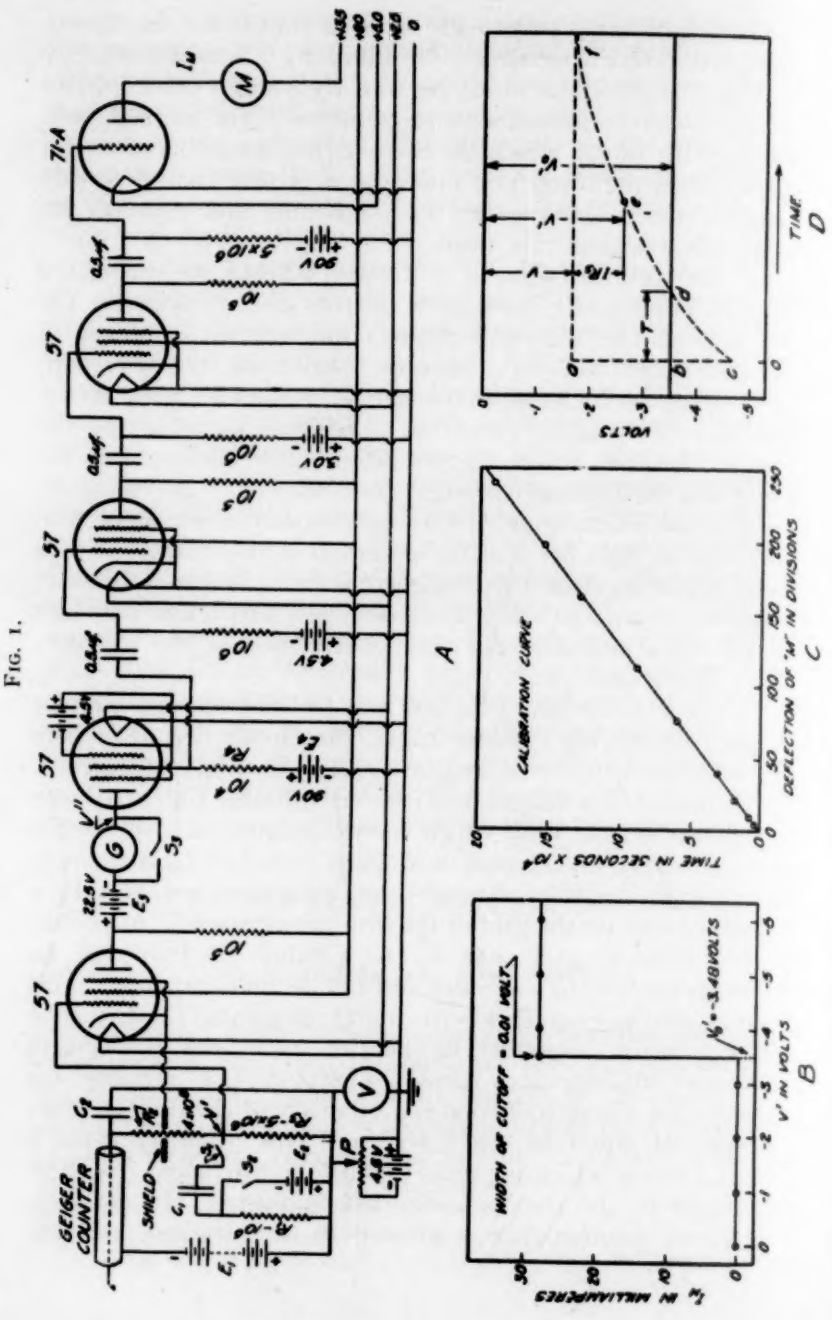
GEIGER COUNTER
SHIELD
57
71-A
WIDTH OF CUTOFF = 0.01 VOLT
V' = -3.48 VOLTS
CALIBRATION CURVE
TIME IN SECONDS X 10⁴
DEFLECTION OF 'M' IN DIVISIONS
VOLTS
TIME
A
B
C
D

FIG. 1.

completion of such a pulse in V' restores all the potentials to very near their initial values and hence renders the circuit capable of responding to subsequent pulses.

Figure 1*C* is a calibration curve in which the throw of M is plotted as a function of τ. This curve was obtained by analyzing negative pulses whose characteristics were accurately known. These pulses were produced by the calibrating unit which, when not in use, is disconnected from the circuit at S_1.

Figure 1*D* shows the method of obtaining the size and shape of a uniform pulse which repeats itself in V' at not too frequent intervals. The entire pulse *abcdef* is shifted up and down with respect to the value V_0' by moving the dial of the potentiometer P. For each position thus obtained, the time T is read directly from the throw of M and, with the data from a series of such positions, the pulse can be accurately plotted.

The essential characteristic of the entire circuit is supplied by the first two tubes, the remaining three serving only to sharpen the cut-off and increase the magnitude of the output current. If only two tubes are used, a sensitive galvanometer is required at G, whereas if five tubes are used, the galvanometer at M may be less sensitive and of the portable type.

For all values of $V' > V_0'$ the plate potential on the second tube is negative and the plate current is zero. At $V' = V_0'$ this plate potential becomes positive, the plate current increases sharply and, at the same time, the screen grid current decreases sharply. This action transmits a positive pulse to the third tube which, in turn, gives a negative pulse to the fourth tube. Since this negative pulse is some 30 volts more than is necessary to turn the fourth tube completely off, the grid of the power tube receives a constant positive potential which increases its plate current from less than 3.0×10^{-9} amperes to 2.8×10^{-2} amperes.

The shield around resistance R_2 reduces the coefficient of induction between its high and low sides and thus prevents the production of an inductive pulse at the instant the counter breaks down.

The circuit was used for three types of pulse analysis: (1) the determination of maximum pulse size as a function of counter potential and central wire capacity; (2) the distri-

bution of pulse sizes in two counters having different dimensions; (3) the effect of counter potential and RC value of the counter circuit on the shape of the recovery curve. For these determinations, two argon filled counters at 7 cm. pressure were used. Both had a diameter of 1 cm. and lengths of 3 and 15 cm. respectively.

In experiment (1) it was found that the size of the pulse was equal to the difference between the counter potential and the starting potential, providing that this difference was not greater than 200 volts. The same result was obtained when condenser C_2 was increased from 10 mmf. to 110 mmf.

In experiment (2), pulses from the short counter did not vary more than 4 per cent. from the size of the maximum, while pulses from the long counter showed a voltage range of 24 per cent.

The results of experiment (3) indicated that the recovery of a counter under normal operating conditions is purely exponential and starts almost immediately after the breakdown. If the counter potential is too high, however, the discharge maintains itself for a relatively long period of time, after which the potential of the wire recovers exponentially.

In conclusion, we wish to express our appreciation to Dr. W. F. G. Swann for his criticism and advice during this investigation. We are also indebted to various members of the Bartol Staff for many helpful discussions on the subject of counter phenomena.

THE NATURE OF THE COSMIC RADIATION.*

BY

W. F. G. SWANN, Director.

A view which maintains that the primary cosmic radiation is of a charged corpuscular nature has to face the experimental existence of an approximately exponential absorption law, and at the same time a state of affairs in which each ray has a definite range. Over this range it produces ionization at a more or less constant rate which is of the same order of magnitude for an energy of 10^9 volts as for an energy of 10^6, at which latter energy it has only a meter or so of its range

* *Physical Review*, April 15, 1935.

left. It is only in this last meter, and indeed in the last part of that meter, that the ionization per centimeter amounts appreciably, and the total amount of ionization in this richly ionizing region is relatively small. On such a view the increase of cosmic-ray intensity with altitude is to be attributed to the softer, that is smaller-energy rays, ending their paths at altitudes which are greater the less the energy. If we define the cosmic ray intensity I_θ for the zenith angle θ as the number of rays passing per second per unit solid angle per square centimeter of area with plane perpendicular to the direction defined by θ, then the exponential law demands that $I_\theta = Ae^{-\mu R}$, where R is the effective path length corresponding to the direction θ. The number of the above rays which are absorbed in the range R to $R + dR$ is the number which *enter the atmosphere* within the limits specified with energies between E_0 and $E_0 + dE_0$ determined by R and $R + dR$. This conclusion holds whatever may be the nature of the loss of energy by the rays provided only that it is sufficiently continuous along the path that rays of the same energy do not have a statistical distribution of ranges varying over limits which are appreciable compared with the effective thickness of the atmosphere. If R is proportional to E_0, say $R = \beta E_0$, as would be the case where the energy loss occurred by a uniform ionization per centimeter of path, the exponential nature of I_θ would involve an exponential law of the form $\beta Ae^{-\mu\beta E_0}dE_0$ for the number of rays entering the atmosphere within the prescribed limits and having energies between E_0 and $E_0 + dE_0$. The existence of such a state of affairs would be rather remarkable, and even though the energy loss were more complicated than that corresponding to uniform ionization, so that R might not be proportional to E_0, the exponential nature of I_θ would necessitate a peculiar law of energy distribution for which there would seem to be no obvious reason. It would be strange, indeed, if such law as existed should conspire in form to produce the relatively simple exponential law for I_θ.

However, the most significant feature is that, as we shall show, regardless of the nature of the energy loss, provided only that we measure intensity by the corresponding number of primary rays, or something proportional thereto, *the*

existence of an exponential law for intensity necessitates that the quality of the radiation shall be the same at all altitudes. In contrast to what seems to be usually implied there is no such thing as the soft rays being found in proportional excess of the hard rays at high altitudes. Rays which are hard at high altitudes are rays which are softer (in the sense of smaller energy) at sea level.

The reason for the foregoing statement is as follows. Let I_θ be the intensity for the direction θ, as above defined; so that, after path lengths R_1 and R_2 through the atmosphere in the direction θ, we have respectively

$$I_{\theta_1} = Ae^{-\mu R_1}; \qquad I_{\theta_2} = Ae^{-\mu R_2}. \tag{1}$$

Thus

$$\frac{I_{\theta_1} - I_{\theta_2}}{I_{\theta_1}} = I - e^{-\mu(R_2 - R_1)}. \tag{2}$$

The exponential nature of (1) has resulted in $(I_{\theta_1} - I_{\theta_2})/I$, depending only upon $R_2 - R_1$. Now $I_{\theta_1} - I_{\theta_2}$ is the number of rays which, within the prescribed limits of angle, etc., disappear in the distance $R_2 - R_1$. These are the rays which are within $R_2 - R_1$ of the end of their range; and this fact *characterizes* their energy range and the upper limit of that range. Equation (2) tells us that, for the prescribed limits of angle, etc., *the number of rays below a certain assigned energy bears to the total number of rays a ratio which is independent of everything but the energy range specified; and, in particular, a ratio which is independent of the altitude.* In other words the *quality* of the radiation is independent of altitude. *The only effect of increased altitude is to increase the number of rays of all energies in the same proportion.*

Since on the foregoing views the quality of the radiation would be independent of altitude, all phenomena produced by the radiation should increase with altitude simply in proportion to the intensity as measured by the number of primary rays. The numbers of secondaries of all classes should increase with altitude in proportion to the primaries, and so, if the secondaries represent the things measured for the most part by our counter and ionization apparatus, the measured intensities should follow an exponential law. Moreover, the number of bursts (Hoffmann stösse) of all sizes, in

lead for example, should increase exponentially with altitude in the *same proportion as the cosmic ray intensity itself*. The last named conclusion is drastically in opposition to the experiments of the Montgomeries [1] who found a twenty-five fold increase of stoss production in lead at the altitude of Pike's Peak as compared with a five-fold increase of the radiation itself.

COINCIDENCE COUNTER STUDIES OF THE VARIATION OF INTENSITIES OF COSMIC RAY SHOWERS AND VERTICAL RAYS WITH BAROMETRIC PRESSURE.[1]

BY

E. C. STEVENSON * and THOMAS H. JOHNSON.

The ratio of the frequency of occurrence of cosmic ray showers to the total cosmic ray intensity has been found by several observers [2, 3, 4, 5] to increase with elevation above sea level. Coincidence counter studies by Johnson indicated an apparent absorption coefficient [6] for simple showers of 0.5 per meter of water and Rossi found changes in the intensities of slightly more complex showers corresponding to an absorption coefficient of 0.65 per meter of water. As further confirmation of these findings we have determined the dependence of shower intensities upon barometric pressure as it varies at a single station.

Three bundles of counters were used, each containing three counters in parallel. The sensitive volume of a single counter was 20 cms. long by 2.5 cms. diameter. Each bundle was incased in an aluminum tube 9 cms. in diameter. Coincidences between bundles were selected and recorded by means

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[1] C. G. and D. D. Montgomery, *Phys. Rev.*, March 15, 1935.

[1] Presented at the Washington Meeting of the American Physical Society, 1934. *Phys. Rev.*, **45**, 758, 1934.

* At present Research Fellow in Physics at Harvard University.

[2] T. H. Johnson, *Phys. Rev.*, **45**, 569, 1934; *Phys. Rev.*, **47**, 318, 1935.

[3] B. Rossi and S. de Benedetti, *Ricerca Scientifica*, **5**—I, 594, 1934.

[4] D. D. Montgomery and C. G. Montgomery, *Phys. Rev.*, **47**, 339, 1935.

[5] R. D. Bennett, G. S. Brown, H. A. Rahmel, *Phys. Rev.*, **47**, 339, 1935.

[6] $\mu = (1/I)dI/dh$.

of a circuit already described.[7] Recording dials were photographed automatically at intervals of one hour and barometric pressures for corresponding times were obtained from the reports of the Philadelphia Branch of the U. S. Weather Bureau. The apparatus was operated in a thin wooden structure on the roof of the Bartol Laboratory approximately 100 meters above sea level.

In the first run the tubes were arranged in a triangle and were covered by a lead plate $10 \times 25 \times 1.2$ cms.[3]

In calculating the average barometer effect all of the shower rates corresponding to each 0.1 inch interval of the barometer have been averaged and the probable error of each average has been computed in the usual way from the dispersion. The best linear relation between shower rates and barometer was found by a least squares solution in which each point was weighted inversely as the square of its probable error. From the solution we find a barometer effect for this arrangement of counters of 0.00542 ± 0.00027 per mm. mercury, corresponding to 0.41 per meter of water. This is in fair agreement with the value found by change of elevation.

We have likewise determined the barometer coefficient of the vertical rays, using an aligned arrangement of the same counters. In this case the outside counters were separated 25 cms. and the arrangement included rays within 17 degrees either side of the vertical in one dimension and 38 degrees in the other. From the least squares solution we find a barometer effect of 0.00362 ± 0.00044 per mm. mercury or 0.28 per meter of water. According to the four component analysis of Bowen, Millikan and Neher [8] the average vertical absorption coefficient at sea level should be 0.325 per meter of water which agrees satisfactorily with our value.

These experiments have confirmed our expectation that the shower intensities would have a higher barometer effect than the total radiation. However for added confirmation a third experiment was made with a triangular arrangement of three counters, two of which were vertical. In this case the double coincidences of two vertical counters were recorded simultaneously with the triple coincidences and the ratio of

[7] T. H. Johnson and J. C. Street, JOUR. FRANK. INST., **215**, 239, 1933.
[8] I. S. Bowen, R. A. Millikan and H. V. Neher, *Phys. Rev.*, **44**, 264, 1933.

triples to doubles was computed for each hourly interval. The ratios were then subjected to an analysis similar to that described above. By least squares analysis, we find a barometer effect for the ratio of 0.0019 ± 0.00079 per mm. mercury. It is noted that the barometer effect for the ratio is equal, within the probable errors, to the difference $0.0054 - 0.0036 = 0.0018$ of the barometer effects found for showers and verticals individually.

We conclude that the showers at sea level are either produced to a greater extent by a soft component of the primary radiation which becomes filtered out to a greater extent in the case of the higher barometric pressures, or, as suggested by Swann,[9] the intensity of showers in equilibrium with a corpuscular primary radiation is greater for lower barometric pressures where average energies are greater.

[9] W. F. G. Swann, *Phys. Rev.*, **46**, 828, 1934; **47**, 250, 1935.

Preserving Fruit with Iodine.—(*Chemical Industries*, Vol. 34, p. 227.) The Low Temperature Research Station, Cambridge, England has investigated the possibility of using iodized wrappings for fruit that is being stored. The wrappers were made by treating tissue paper with a definite volume of iodine solution so that a covering about 10 inches square contains approximately one-thousandth of an ounce of free iodine. Laboratory tests show that storage rots of fruit can be considerably reduced by this kind of wrapping, while the appearance and ripening of most varieties are not impaired.

C.

A Flowering Enterprise.—(*I. & E. C.* News Edition, Vol. 13, p. 115.) Mahura flowers, which grow abundantly in Central India, are now being used as a source of rectified spirit by a chemical works located at Baroda in that vicinity. The juice which contains grape sugar is expressed from the flowers by macerators. It is then allowed to ferment in vats with microscopically pure yeast prepared in the laboratories of the works. The greatest problem was that of eliminating the objectionable odor of the Mahura flowers. This the chemists finally succeeded in doing.

C.

Stretching the Earth.—(*Science*, Supplement, Vol. 81, Mar. 8.) PROFESSOR HARLAN T. STETSON AND DR. A. L. LOOMIS have discovered that tides in the solid earth may alter the distance between the North American and European continents by as much as 63 feet. These tides in the earth are believed to be caused by the moon through its gravitational pull much in the same manner as it causes ocean tides. A clue to the existence of such earth expansion and contraction was that the observed discrepancies in astronomically checked clocks in Europe and North America increased and decreased regularly with changes in the moon's position.

It was at first thought that changes in the amount of time required for transatlantic radio transmissions might be the cause of the discrepancies, or that the moon might lift the Heaviside ionized layer which reflects radio waves and thus gives them a longer distance to travel. A check on these possibilities showed them probably to be incapable of accounting for the large size of the time discrepancies. Incidentally, in considering these aspects it was found that the average length of time required for transatlantic transmission is approximately four one-hundredths of a second.

C.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, APRIL 17, 1935.

The regular monthly meeting of the Institute was called to order on Wednesday, April seventeenth at eight-fifteen p.m. by the President of the Institute, Mr. Nathan Hayward.

The President called upon the Secretary for the presentation of any business. The latter stated that it was customary to elect to Honorary Membership in the Institute those persons to whom Franklin Medals had been awarded. In accordance with this practice, he moved that Dr. Albert Einstein and Sir Ambrose Fleming be elected to Honorary Membership. The motion was seconded and adopted unanimously by the vote of the members of the Institute present.

The President then introduced Dr. W. F. G. Swann, Director of the Bartol Research Foundation, who presented his annual report of the activities of the laboratory. Dr. Swann was heard with absorbed interest by an unusually large audience.

The meeting was adjourned at ten-fifteen p.m. with a rising vote of thanks and appreciation for Dr. Swann's brilliant paper.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, April 10, 1935.)

HALL OF THE COMMITTEE,
PHILADELPHIA, APRIL 10, 1935.

MR. CHARLES H. MASLAND, 2ND, *in the Chair.*

The following reports were presented for first reading:

No. 2991: Heat Insulation by Metal Foil.
No. 2997: Electric Resistance Element.
No. 2999: Magnaflux.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

RESIDENT.

MR. MARTIN H. FEDDERN, Electric Meter Tester, Philadelphia Electric Company, Philadelphia, Pa. For mailing: 234 East Johnson Street, Philadelphia, Pa.

MR. CHARLES R. FREDERICK, Chemist, Keasbey and Mattison Company, Ambler, Pa.

MR. LOUIS MALTER, Physicist, RCA Victor Company, Camden, New Jersey.
MR. ROSS L. MCLELLAN, District Manager, Worthington Pump and Machinery Company. For mailing: 324 Conestoga Road, Wayne, Pa.
MR. NILS A. Sahlin, President, Sahlin Color Company, Camden, New Jersey. For mailing: 930 Stokes Avenue, Collingswood, N. J.

NON-RESIDENT.

MR. HERBERT M. COSTER, Superintendent of Acid Plants, U. S. Naval Powder Factory, Indian Head, Maryland.

STUDENT.

MR. EDWARD J. CASEY, 7017 Llanfair Road, Bywood, Upper Darby, Pa.
MR. JOHN DOERING, 6627 Greene Street, Philadelphia, Pa.
MR. JOHN DURA, 1434 North Seventh Street, Philadelphia, Pa.
MR. HARRY T. ENSSLER, 2081 East Monmouth Street, Philadelphia, Pa.
MR. I. RALPH LANDAU, 4269 Leidy Avenue, Philadelphia, Pa.
MR. JOHN M. MUROFF, 1756 North Lindenwood Street, Philadelphia, Pa.
MR. EDWARD S. OLSHO, 535 Pelham Road, Philadelphia, Pa.
MR. JAMES C. REID, 503 Owen Road, Ardmore, Pa.
MR. WALTER A. ROTH, 8311 Ardleigh Street, Philadelphia, Pa.
MR. HORACE WARD, 2405 North Nineteenth Street, Philadelphia, Pa.
MR. THOMAS YANO, 3807 Spruce Street, Philadelphia, Pa.
MR. BRUCE H. ZACHERLE, 4905 Pulaski Avenue, Philadelphia, Pa.

MUSEUM MEMBERSHIP.

FAMILY.

MR. EUGENE KLEIN, 200 South Thirteenth Street, Philadelphia, Pa.

INDIVIDUAL.

MISS GERTRUDE M. GOODWIN, Sharon Hill, Pa.
MR. EDWARD F. GOULD, Kent Road, Wyncote, Pa.
MR. WALTER W. LEIGHT, JR., Packard Building Philadelphia, Pa.
MR. ROY A. MEEKER, 441 Carteret Street, Camden, New Jersey.
MR. THOMAS W. MORAN, 30 West Eagle Road, Upper Darby, Pa.
MRS. THOMAS W. MORAN, 30 West Eagle Road, Upper Darby, Pa.
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MR. WILLIAM MCHESS, Richwood Road, Mullica Hill, N. J.
MR. IRVING LINER, 3316 Race Street, Philadelphia, Pa.
MR. JACK MEGONEGAL, 5932 Oxford Street, Philadelphia, Pa.
MR. JEROME E. ORNSTEIN, 1613 Spruce Street, Philadelphia, Pa.
MR. CHARLES N. RAY, 412 Bainbridge Street, Philadelphia, Pa.
MR. RICHARD B. SINGER, 4224 Chester Avenue, Philadelphia, Pa.
MR. REX P. WILLSON, St. Davids, Pa.

MISS ROBERTA WILSON, 334 Kent Road, Bala-Cynwyd, Pa.
MR. WILLIAM ZACHARIAS, 1733 North Redfield Street, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. A. W. BERRESFORD, 418 Central Park West, New York City, N. Y.
MR. THOMAS BILYEU, 2390 S. W. Madison Street, Portland, Oregon.
MR. M. M. BORDEN, 310 Lees Avenue, Collingswood, N. J.
MR. PAUL EGLICK, 4933 Gransback Street, Philadelphia, Pa.
MR. JOHN GRIBBEL, 306 Bulletin Building, Philadelphia, Pa.
MR. CARROLL B. NICHOLS, Foedisch Coal Company, 1169 Broad Street Station Building, Philadelphia, Pa.
DR. LUDWIG W. WASUM, 225 East Penn Street, Germantown, Phila., Pa.
MR. FRANCIS R. WADLEIGH, 1026 Fifteenth Street N. W., Washington, D. C.
MR. W. WILLCOX, 508 Lafayette Road, Merion, Pa.
MR. ALFRED WOLF, 2607 Boston Place, Tulsa, Oklahoma.

NECROLOGY.

Mr. John S. Wilson, Pitman, N. J.

LIBRARY NOTES.

RECENT ADDITIONS.

BECKER, R. Theorie der Elektrizität. Neubearbeitung des Werkes von M. Abraham. Band I: Einführung in die Maxwellsche Theorie der Elektrizität. Zehnte Auflage. 1933.

CLARK, C. H. DOUGLAS. The Electronic Structure and Properties of Matter. An Introductory Study of Certain Properties of Matter in the Light of Atomic Numbers. Being Volume I of a Comprehensive Treatise of Atomic and Molecular Structure. 1934.

COMPTON, ARTHUR H., AND SAMUEL K. ALLISON. X-Rays in Theory and Experiment. Second Edition of X-Rays and Electrons by Arthur H. Compton. 1935.

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EDDINGTON, SIR ARTHUR. New Pathways in Science. Messenger Lectures, 1934.

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BOOK REVIEWS.

PRINCIPLES OF PHASE DIAGRAMS, by J. S. Marsh, with a foreword by John Johnston. 193 pages, illustrations, 15 × 23 cms. New York and London, McGraw-Hill Book Company, Inc. 1935. Price $3.00.

One of the monograph series of Alloys of Iron Research, this book was written to obviate the necessity of discussing questions of interpretation of phase diagrams and diagrams of state in each of the monographs. It is an admirable attempt to make clear, in as easy a manner as possible, such diagrams to the great majority of those who come in contact with them and who do not know just what such diagrams mean. Among the reasons for this lack of understanding are the difficulties in obtaining suitable literary treatments leading up to and including the subject, and the availability of suitable literature.

The book is divided into two parts, (1) to show what the diagrams mean and (2) to show examples of diagrams. In the first part allusion is made to the underlying principles of the science of thermodynamics to which the diagrams belong. An outline of basic thermodynamics is given, followed by a treatment on some exact statements of basic thermodynamics. This corresponds with Guggenheim's "Modern Thermodynamics by the Methods of Willard Gibbs."

The second part of the book consists of three chapters dealing with systems of one to three components. It is demonstrated that all diagrams are related and that the complex are deduced from the simple by a series of steps. These chapters illustrate the principles schematically and in order to bridge a seeming gap between the schematic and the real, a few examples of real diagrams are cited in another, the last chapter. They serve to illustrate the meaning of the principles.

The book treats on a rare subject and should suitably fill a niche in the storeroom of tools of knowledge on subjects in which there is a distinct need for it.

R. H. OPPERMANN.

HISTORY OF RENSSELAER POLYTECHNIC INSTITUTE, 1824–1934, by Palmer C. Ricketts. 293 pages, plates, 15 × 22.5 cms. New York, John Wiley & Sons, Inc. London, Chapman & Hall, Ltd. 1934. Price $3.50.

To read of the handicaps and obstacles overcome by the founders of our country fills one with greater appreciation of the advantages available today. Surely the men who visualized and who were ambitious enough to overcome the almost insurmountable difficulties of the early days of our country to establish a school of science such as Rensselaer were men of outstanding and limitless capacities. Such men were Stephen Van Rensselaer and Amos Eaton.

The Rensselaer School, afterwards Rensselaer Polytechnic Institute, was founded by Stephen Van Rensselaer in 1824 when there was little enthusiasm for the diffusion of scientific knowledge. The founder, however, was wise enough to discover the genius of Amos Eaton and to employ him to deliver a course of popular lectures and afterwards appoint him as head of the school. Eaton was a geologist, botanist and chemist and these qualifications together with his unexcelled ability as an instructor and inspirer made the name of the Rensselaer School foremost. He developed in the school the first engineering curriculum to be created in the country and the school gave the first engineering degree—that of civil engineer in 1835.

It is interesting to read that a circular issued by Eaton dated October 29, 1828 contained notice that "a lady, well qualified for the duty, will take charge of two experimental courses in chemistry and natural philosophy, in each year for ladies." Authorities of the school seemed to have advanced ideas in regard to the education of women.

B. Franklin Green, a former pupil of Eaton, in 1849–50 reorganized the engineering course, forming the basis of courses of that kind in almost every engineering school afterwards established in this country. Forty years before the departments of architecture were created in the universities of Pennsylvania, Harvard and Columbia, he published in his classic pamphlet entitled "The True Idea of a Polytechnic Institute," a curriculum for an architectural course.

That the energetic persuits of Eaton and Green to establish and maintain a school surpassed by none have been continuously followed up to the present day is well illustrated in this book. Not only the growth of the school but the quality of its product gives evidence of its high standing.

The book should prove interesting and valuable to all students of education. The style in which it is written makes it easy to read and impressive.

R. H. OPPERMANN.

HANDBOOK OF TECHNICAL INSTRUCTION FOR WIRELESS TELEGRAPHISTS, by H. M. Dowsett, 5th edition. 572 pages, illustrations, 14 × 22 cms. London, Iliffe & Sons, Ltd. Price 15 shillings.

This book is especially written for British radio operators on ship board and others. It contains the necessary technical instruction for prospective operators to receive their certificate of approval as well as providing the necessary information for the maintenance and operation of British marine radio apparatus.

Beginning with fundamentals it treats on the electric charge and condenser and proceeds on through the fundamentals of direct and alternating currents to generators and oscillatory circuits. It describes various types of spark transmitters, aerials, and receiving apparatus. From this it goes into vacuum tube transmission and reception including short wave. Direction finders, distress call apparatus, radio telephony, lifeboat and emergency outfits, all are given thorough treatment. It does not delve deeply into design calculations but keeps closely to the more practical line of operation and maintenance. A knowledge of trigonometry and logarithms is helpful for thorough understanding in some parts of the book. The symbols and diagrams used are of course British.

Although the book is intended for British users, it can also be profitably perused by Americans and others. Amateurs as well as commercial radio men will find that the treatment of theory is very clearly and impressively made. Radio technicians in general can obtain a knowledge of other makes of apparatus which cannot be gotten otherwise without difficulty.

R. H. OPPERMANN.

DIE ELEKTRISCHEN MASCHINEN, Band III, Berechnung und Bemessung, von Dr.-Ing. M. Liwschitz. 409 pages, illustrations, 15 × 23 cms. Leipzig und Berlin, B. G. Teubner, 1934. Price RM. 22.50.

This is volume III of a set of text books treating on electrical machinery. It is devoted to the more advanced study of calculations and measurements brought up to date as the result of new researches and scientific work.

The first four chapters deal in detail with the magnetic influence, the field in electrical rotating machines and transformers, the various losses and the heating of electrical machines. Chapter V is devoted to the current and circlar diagrams of the asynchronous machine which precedes an excellent discussion on the transformer. This part includes all of the main factors which affect losses. Following this are chapters on the asynchronous machine, the synchronous machine and the direct current machine. There are practical examples of calculations on a single phase railway motor, a three phase motor and others. A bibliography of 605 references is appended which is so divided as to refer to the subjects treated in each chapter.

Assembled with the coöperation of Dr.-Ing. H. Raymond of Berlin, the book makes use of 307 figures and illustrations to make plain its treatment. It is a valuable work for the student as well as the practicing engineer and is compact, containing only the necessary data for detailed and clear understanding.

R. H. OPPERMANN.

CUGLE'S TWO-MINUTE AZIMUTHS, LATITUDE 0° TO 35°, DECLINATION 0° TO 23°, SAME AND CONTRARY NAMES, by Charles H. Cugle, 613 pages, 21.5 × 28.5 cms. New York, E. P. Dutton & Co., Inc., price $5.00.

This is an American Azimuth Table of two minute intervals. The author presents it with the belief that the two minute time interval will eliminate interpolations required in the finding of Azimuths. The full range of declinations for the Sun are given. The table embraces the Latitudes of 0° to 35° and Declinations of 0° to 23°.

The computation of time Azimuths is explained by means of six rules and examples.

This book of tables should satisfy a need felt by navigators and others whose interests lie in this direction.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 498, Improved Airplane Windshields to Provide Vision in Stormy Weather, by William C. Clay, 19 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

The results of an investigation made in the N.A.C.A. 7- by 10-foot wind tunnel to determine possible improvements in the design of airplane windshields, particularly with respect to the pilot's vision from the cabin in stormy weather, are reported.

It was found practicable to design openings in airplane windshields that will permit some unobstructed view from the cabin and yet shield the pilot from wind and rain.

Openings up to 2 inches in width across a flat front panel in vertical or sloping windshields will permit a view directly forward without direct raindrops entering the opening if a small deflecting airfoil is mounted ahead of the windshield. A slight increase of the fuselage static pressure is necessary to keep wind and indirect water drops from entering this style of opening.

It was found possible to design a V-front windshield that utilizes raindrop deflection through small angles to provide vision through open windows on either side of the cabin. Adequate vision can be obtained within normal limits of head movement for nearly the entire forward hemisphere without any appreciable amount of rain or wind entering the cabin, even under atmospheric conditions favorable to ice formation.

Improvements made in the design of several windshield types are described and information given on the air flow about each arrangement.

Report No. 506, Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. V.-Clark Y Biplane Cellule—N.A.C.A. Cowled Nacelle—Tractor Propeller, by E. Floyd Valentine, 17 pages, plates, tables, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

This report is the fifth of a series giving the results obtained in the N.A.C.A. 20-foot wind tunnel on the interference drag and propulsive efficiency of nacelle-propeller-wing combinations. The first report gave the results of the tests of an N.A.C.A. cowled air-cooled engine nacelle with tractor propeller located in 21

positions with reference to a thick monoplane wing. The second and third reports gave the results with several engine cowlings and nacelles with tractor propeller located in four positions with reference to the thick wing and a Clark Y wing, respectively. Results with several engine cowlings with tandem nacelle arrangements in various positions with reference to the thick wing were given in the fourth report. The present report gives results of tests of an N.A.C.A. cowled air-cooled engine nacelle with tractor propeller located in 12 positions with reference to a Clark Y biplane cellule.

The lift, drag, and propulsive efficiency were determined at several angles of attack in each nacelle position. The net efficiency was computed by the method of the first report. The results are compared with those for a monoplane wing of the same section and chord given in the third report.

The best results were obtained with the propeller, 50 per cent. of the chord directly ahead of the upper wing. The same position relative to the lower wing is nearly as good. Positions about half-way between the two wings with the propeller near the leading edges are the poorest. There is a fair agreement between the results with biplane combinations and those for similar monoplane combinations.

Report No. 508, Analysis of 2-Spar Cantilever Wings with Special Reference to Torsion and Load Transference, by Paul Kuhn. 23 pages, tables, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1935. Price ten cents.

This paper deals with the analysis of 2-spar cantilever wings in torsion, taking cognizance of the fact that the spars are not independent, but are interconnected by ribs and other structural members. The principles of interaction are briefly explained, showing that the mutual relief action occurring depends on the "pure torsional stiffness" of the wing cross section. Various practical methods of analysis are outlined. The "Friedrichs-von Kármán equations" are shown to require the least amount of labor. These equations were originally derived for wings that owe their torsional stiffness to the individual torsional stiffnesses of the spars; it is shown, however, that the equations apply also to wings in which the torsional stiffness is due to drag bracing—wires or stressed skin—arranged in two planes.

Numerical examples by the several methods of analysis are given and the agreement between the calculation and experiment is shown. In the case of a trussed-spar structure the results are practically equivalent to the results of standard least-work calculations which treat the structure as a pin-jointed space framework, but they can be obtained with so much less labor that the analysis may be made as a routine design procedure.

Report No. 509, General Equations for the Stress Analysis of Rings, by Eugene E. Lundquist and Walter F. Burke, 10 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price five cents.

In this report it is shown that the shear, axial force, and moment at one point in a simple ring subjected to any loading condition can be given by three independent equations involving certain integrals that must be evaluated regardless

of the method of analysis used. It is also shown how symmetry of the ring alone or of the ring and the loading about 1 or 2 axes makes it possible to simplify the three equations and greatly to reduce the number of integrals that must be evaluated.

Application of the general equations presented in this report to practical problems in the stress analysis of rings makes it possible to shorten, simplify, and systematize the calculations for both simple and braced rings. Three illustrative problems are included to demonstrate the application of the general equations to a simple ring with different loadings.

Bibliography of Aeronautics, 1931. 312 pages, 18 × 26 cms. Washington, Superintendent of Documents, 1935. Price fifty cents.

The Bibliography of Aeronautics for 1931 covers the aeronautical literature published from January 1 to December 31, 1931. The first Bibliography of Aeronautics was published by the Smithsonian Institution as Volume 55 of the Smithsonian Miscellaneous Collections and covered the material published prior to June 30, 1909. Supplementary volumes of the Bibliography of Aeronautics for the subsequent years have been published by the National Advisory Committee for Aeronautics. They are the Bibliography of Aeronautics for the years 1909–1916, 1917–1919, 1920–1921, 1922, 1923, 1924, 1925, 1926, 1927, 1928, 1929, and 1930.

As in previous volumes, citations of the publications of all nations are included in the languages in which these publications originally appeared. The arrangement is in dictionary form with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of the cost of presentation but an attempt has been made to give sufficient cross reference for research in special lines.

R.

THE NITROGEN SYSTEM OF COMPOUNDS, by Edward Curtis Franklin, 339 pages, illustrations, 15.5 × 23.5 cms. New York, Reinhold Publishing Corp., 1935. Price $7.50.

The Monograph Series of the American Chemical Society continues the good work of encouraging authorities on various subjects in chemistry to record their knowledge in black and white for the benefit of others. Literally, this latest member of the series describes how liquid ammonia may be used like water—at least, as participants in a chemical reaction. More properly stated: There is now in Monograph form a description of the "Nitrogen System of Compounds," a system whose conscious inception dates from the autumn of 1896. In contrast to the well-known oxygen system, the most universally occurring member of which is water, the nitrogen system may claim ammonia as its most cosmopolitan representative.

The author of the "Nitrogen System" is recognized throughout the length and breadth of the chemical fraternity as an outstanding authority on the subject. To hear him discuss it is to lead the unsuspecting listener into thinking the Nitrogen System is simplicity itself and that if one has learned to manipulate the oxygen compounds at will, the handling of ammonia and its derivatives will come more or less as second nature. However, it is not so simple as all that. Ammonia must be retained in properly constructed vessels and the sensitivity of many de-

rivatives demand that the experimenter acquire a more complicated technique than he needed heretofore. Although the analogy between the oxygen and nitrogen compounds is relatively easy to point out, the conditions under which their respective reactions take place do not show a similar degree of resemblance and a Monograph of this size and completeness really is necessary if others are to benefit as fully as possible.

The layout of the subject matter is along more or less conventional lines. The first chapter covers the properties of liquid ammonia and from there on it seems to the reader that nitrogen, through the medium of ammonia, has been introduced into every conceivable place that has been occupied by oxygen. Oddly enough, the most valuable section of the book does not bear the status of a chapter, but comes under the heading of Appendix. Here is given the methods for manipulating liquid ammonia and directions for preparing several metallic derivatives. At a future date, this section well might be expanded into a manual of text-book proportions.

T. K. CLEVELAND

A TREATISE ON MODERN PHYSICS, ATOMS, MOLECULES AND NUCLEI, vol. I, by M. N. Saha, D.Sc., F.R.S., and N. K. Saha, M.Sc. 856 pages, illustrations, tables, 16.5 × 25 cms. Allahabad and Calcutta, The Indian Press, Ltd., 1934. Price 28 shillings.

This very interesting text coming from India is Volume I of a work which gives a concise and up to date account of the series of discoveries which make up the present day Atomic Physics. It is divided into ten chapters, arranged to cover a course of two years. Starting with the experimental study of ions the reader is taken through the treatments on elementary radioactivity, the nature of light, Bohr's theory of the spectrum of hydrogen, the Zeeman effect, periodic classification and principles of atom structure, to magnetism and its theories. So clear are these treatments that it is difficult to pass from one to the other without being inspired to go further and study the original literature recommended at the end of the chapters. Diagrams and plates add much to making the book extremely interesting, especially the former which are presented in an appealing and simple manner. A carefully prepared subject and author index also adds greatly to the value of the book for reference purposes.

Modern ideas of atomic physics are by no means conclusive, for there are yet many issues uncertain. The writing of a book of this kind, bringing the subject matter up to date from the earliest conceptions is by no means an easy task in itself, but to present it in the form of a logical trend of connecting thought in as intelligible a manner as is found in this book, can only be accomplished by masters. The work is authoritative in every respect. Because of its present size, the authors note in the preface that chapters on molecular physics, interaction between matter and light, wave mechanics and nuclear physics are to be included in a second volume. The present volume and the projected volume are to be supplemented with a volume on mathematical physics.

Student and research workers in physics, physical chemistry and astrophysics whether familiar with the subject in its entirety or not will do well to cover this volume. It should be quite popular as a text book as well as a reference volume.

R. H. OPPERMANN.

AN INTRODUCTORY COURSE IN COLLEGE PHYSICS, by Newton Henry Black, Assistant Prof. of Physics, Harvard University and Radcliffe College. 714 pages, illustrations, 14.5 × 22 cms. New York, The Macmillan Company, 1935. Price $3.50.

"Some books," wrote Francis Bacon, "are to be tasted, others to be swallowed, and some few to be chewed and digested." This book should be placed in the last category for all who desire a thorough grounding in fundamental principles. It is needless to emphasize that a proper background is essential for the understanding of the modern aspects of theoretical physics.

The book is planned so as to approach the subject through the span of mechanics from weights and measures to fluids in motion; heat, including temperature and expansion, to heat engines. In this latter treatment steam boilers, steam engines and turbines, and gas engines are all briefly explained making free use of simple drawings and illustrations. Next, magnetism and electricity is discussed to the extent of including the subjects of magnetic and chemical effects of electric current, electric power, induction coils, and electric discharge through gases. Divisions on sound and light, the latter covering radioactivity and structure of matter, concludes the text.

It would be difficult to find a more clearer and simple treatment. The book fulfills its purpose excellently. Every effort is made to assist the reader in digesting its contents. The style of writing, the problems given for making the subject matter more permanently fixed, the summaries of the chapters and the references listed for further study, all illustrate sympathetic understanding of the student.

While the author states that the book furnishes a one year college course for future engineers and physicians, it is not going too far to say that in addition to this the book can be invaluable for home study and for reference purposes.

R. H. OPPERMANN.

DYNAMISCHE BEANSPRUCHUNGEN VON FÖRDERSEILEN, von Dipl.-Ing. H. Herbst unter Mitarbeit von Dipl.-Ing. W. Berke und Dipl.-Ing. H. Schüssler. 140 pages, illustrations, tables, 16.5 × 24 cms. Gelsenkirchen, Carl Bertenburg, 1934.

This is a report on the dynamic properties of cable when used in machinery for lifting weights such as in hoisting or driving machines, derricks, cranes, etc. It is number 5 of a series of works on excavation and mining researches.

After treating briefly with previous work leading up to the starting point of this discussion, the author gives an excellent explanation of the theoretical fundamentals of cable vibration. In it is discussed the resistance offered to vibration and the beginning and acceleration of vibration, and cable vibration between parts of the hoisting machine, such as between the winding spool and the cable pulley.

The main part of the report deals with tests. This begins with treatment of the methods of measurement of Jahnke and Keinath, and proceeds through the subjects of cable expansion measurements and tests to determine the dynamic properties of cables near the weighted part or where the load is fastened.

Every kind of vibration is studied and discussed with clarity and precision. This report should prove of immense benefit to those having to do with cable hoisting operations in mining as well as elsewhere. It is a distinct contribution to the science of mechanics.

R. H. OPPERMANN.

THE METEOROLOGICAL OBSERVER'S HANDBOOK, 1934 edition, published by the Authority of the Meteorological Committee, 152 pages, plates, tables, 15.5 × 25 cms. London, King's Printer, 1934. Price five shillings.

Addressed primarily to observers in the British Isles, this handbook generally follows decisions of International Conferences relating to observations. It represents the experience of those concerned with meterological observations in connection with the Air Ministry of Great Britain and is a complete instruction in the care and manipulation of meterological instruments and in the making of observations, at ground level, both instrumental and non-instrumental.

The book is divided into three parts. Part I contains instructions for the making of observations which constitute the routine of a normal climatological station. This includes a discussion on the requirements of a normal climatological station, its layout, the mounting and use of the mercury barometer, thermometers, rain gauge and sunshine recorder. Everything with regard to eye observations is taken up.

Part II is devoted to self recording instruments such as the barograph, the thermograph, the hair hygrograph and self recording rain gauges. The third part of the book consists of tables necessary in connection with the use of the various instruments as well as tables for reduction of pressures in millibars and inches to mean sea level.

The book is brief and to the point. It, of course, should be of greatest value to British observers, but it has much that should be of interest and benefit to all physicists whose work involves climatological conditions.

R. H. OPPERMANN.

THE PULP AND PAPER INDUSTRY, 1932–1933. Census of Industry. Canada, Department of Trade and Commerce. Dominion Bureau of Statistics, Forestry Branch. 117 pages, 16.5 × 25 cms. Ottawa, King's Printer, 1935. Price, 25 cents.

This detailed compilation of economic and industrial data covers the most important manufacturing industry in Canada, heading the lists in 1933 for gross and net values of manufactured products, number of employees and distribution of wages and salaries. In total capital invested the industry is exceeded only by electric light and power plants. The text is given both in English and French.

Six pages summarize the historical development of pulpwood, wood-pulp and paper production, general information relative to pulpwood, wood-pulp manufacture by the various processes and the characteristics of the products, paper manufacture and types.

The remainder of the English text is devoted to statistics of production (10 pages), of raw materials (3 pages), agencies of production, that is, capital, equipment and capacity of mills, power employed, employment data—salaries, wages, hours (5 pages), and exports and imports of pulpwood, wood-pulp and paper (12 pages). There are 35 tables of detailed statistics and 22 summary tables, altogether a wealth of information, painstakingly assembled. In a few cases data for the United States and other nations are given.

Canadian paper production increased rapidly from 1921 to 1929, then fell away almost as swiftly over the years 1929–1932, a reversal of the trend occurring

in 1933. Newsprint forms the bulk of the tonnage. Newsprint production in the United States has had a much more stable course.

The pulp and paper industry contributed approximately $98,000,000 in 1932 and $90,000,000 in 1933 toward the production of a favorable Canadian trade balance. Products of forest origin have always been more dependable from the point of view of sustaining favorable trade balances than any other comparable group of commodities.

LESLIE R. BACON.

MECHANICS FOR BEGINNERS. By F. Barraclough, M.A., and E. J. Holmyard, M.A., M.Sc., D.Litt., F.I.C. With 92 figures and 8 plates. 214 pages, 12.2 × 18.0 cm. Dent's Modern Science Series. London. J. M. Dent and Sons, Ltd., (E. P. Dutton & Co., Inc., New York). Price $1.00.

As a first book in mechanics this little volume should prove a reasonable success. It is judged to approximate American secondary schools in advancement of treatment. The informal style catches and holds the interest without resort to extravagant window-dressing. General principles are illustrated by examples common to the experiences of all readers. The following discussion of walking illustrates the general level of treatment:

"The difficulty of learning to walk is simply the difficulty of learning how to move one's centre of gravity appropriately. There is no necessity to see a slow-motion film of a person walking to understand what happens: you can find out yourself. Put your left leg forward as you do in walking, but as slowly as possible. You will discover that you fall on to this foot, and have made one step forward in consequence. What has happened is clear. One part of you, viz. your leg, was moving forwards, and your centre of gravity was thus also advancing. Ultimately the vertical line through your center of gravity passed beyond your right foot, so that no upward force of the floor could then act through it. As a result, you over-balanced on to your left foot. Walking is simply a succession of such acts."

The several chapters take up forces, moments, center of gravity, work, machines, density and specific gravity, liquid pressure, gases, speed, velocity, acceleration, Newton's Laws of Motion and a little about energy.

Thus the reader is left in possession of considerable real knowledge. Much care has evidently been used to avoid creation of misapprehensions, though Heaven alone knows how much the Bible itself is subject to misinterpretation.

LESLIE R. BACON.

PRACTICAL SOLUTION OF TORSIONAL VIBRATION PROBLEMS, WITH EXAMPLES FROM MARINE, ELECTRICAL, AND AUTOMOBILE ENGINEERING PRACTICE, by W. Ker Wilson, M.Sc. 438 pages, illustrations, tables, 14 × 22.5 cms. New York, John Wiley & Sons, Inc., 1935. Price $7.00.

The ever increasing demand for the performance of work by rotating machinery brings forth a multitude of problems dealing with rotation of shafts. It is necessary for the designers of this machinery to take into account from every possible angle all that affects its workability and permanency. Much depends, now-a-days, on accuracy of design. As a result sharp focus is centered on every factor. Torsional vibration is one of these factors which demands expert knowledge. The book at hand is an instrument by which it is possible to select data appropriate to particular problems. A set of standard forms suitable for rapid reference can then be built up.

In introducing the subject, the author first describes fundamentals, giving briefly theories. Thereafter is an agreeable blending of theory and practical applications. Under the heading of natural frequency calculations it dwells on such subjects as characteristics of direct coupled electric generating sets to internal combustion engines and marine oil engine installations. Equivalent oscillating systems and determination of stresses due to torsional vibration at non-resonant and resonant speeds are treated in detail. The measurement of torsional vibration amplitudes and stresses is a part of the book that is very interesting. In it is explained the Geiger torsiograph, the D.V.L. torsiograph and others, their operation and how to use the records obtained.

Of similar interest is the treatment on torsional vibration damping devices wherein actual cases are illustrated with various dampers. An appendix gives a method of obtaining the first twelve harmonic components of any periodic function, which should prove quite handy. The index in the back is quite detailed and adds much to the book's practicability.

It is difficult to do complete justice in reviewing this book in emphasizing its usefulness. While the general subject is somewhat specialized its scope is comprehensive. The manner of presentation of the material is admirable. As a text and reference book it is excellent.

R. H. OPPERMANN.

TABLES OF INTEGRALS AND OTHER MATHEMATICAL DATA, by Herbert Bristol Dwight, D.Sc. 222 pages, 14 × 22 cms. New York, The Macmillan Company, 1934. Price $1.50.

A synopsis of compact results including Algebraic, Trigonometric, Exponential, Logarithmic, Hyperbolic and Elliptic functions. An appendix contains tables of numerical values and references to thirty-seven works on mathematics. The subject index concludes the book.

This book should prove to be a very necessary and time saving auxiliary tool to engineers and scientists who need a compact mathematical reference work.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Practical Solution of Torsional Vibration Problems, with examples from marine, electrical, and automobile engineering practice, by W. Ker Wilson, New York, John Wiley & Sons, Inc., 1935, 438 pages, tables, illustrations, 14 × 22.5 cms. Price $7.00.

An Introductory Course in College Physics, by Newton Henry Black, 714 pages, illustrations, tables, 14.5 × 22.5 cms. New York, The Macmillan Company, 1935. Price $3.50.

A Treatise on Modern Physics, Atoms, Molecules and Nuclei, vol. 1, by M. N. Saha and N. K. Saha, 856 pages, illustrations, tables, 16.5 × 25 cms. Allahabad and Calcutta, The Indian Press, Ltd., 1934. Price 28 shillings.

W. C. Röntgen Briefe an L. Zehnder, Mit den Beiträgen, Geschichte seiner Entdeckung der Röntgenstrahlen und Röntgens Einstellung zur Renaissance der klassischen Physik, von Dr. Ludwig Zehnder. 198 pages, 16 × 23 cms. Zurich, Rascher & Cie., 1935.

Radio-Électricité Generale, Tome I, Etude des Circuits et de la Propagation, par R. Mesny, 375 pages, illustrations, 16 × 25.5 cms. Paris, Etienne Chiron, 1935.

La Theorie d'Einstein Dementie par l'Experience, par E. Carvallo, 55 pages, 14.5 × 22.5 cms. Paris, Etienne Chiron, 1934.

Electro-Acoustique, par Ph. Le Corbeiller. 87 pages, illustrations, 16.5 × 25 cms. Paris, Etienne Chiron, 1934.

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